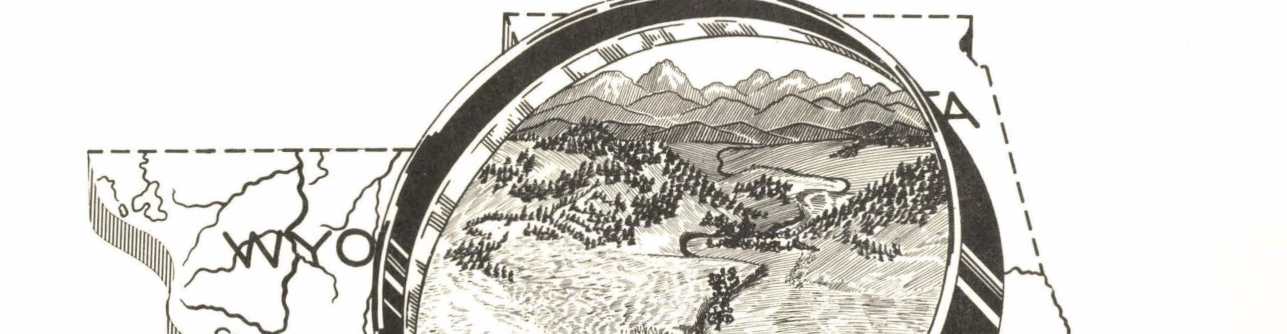
1950 Annual Report



FOREST SERVICE
U S
DEPARTMENT OF AGRICULTURE

Rocky Mountain Forest & Range Experiment Station

W. G. McGinnies, Director
Fort Collins, Colorado

THE COVER

The Rocky Mountain Forest and Range Experiment Station serves the States of Colorado, Wyoming, South Dakota, Nebraska, and Kansas. As we scrutinize this large block of our country, there appear countless examples of the close relationship of water, grass, and timber --- three important segments of our national wealth. Research aimed at more productive use of these resources contributes to our strength and security.

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

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Annual Report-1950

March 20, 1951

Dear Sir:

We are pleased to provide you with a copy of our 1950 Annual Report. The report summarizes the recent research findings of the Rocky Mountain Forest and Range Experiment Station.

It is believed that you will find much to interest you in the fields of range, forest, and watershed management research. This year we have placed particular emphasis on bringing out information of value to the defense program. We have tried to show where Research can point the way toward more efficient utilization of natural resources and, at the same time, rebuild those that have been subject to past depletion.

If you desire more information on the subjects covered in this report, we will be very glad to supply you with any available publication or other material.

Very truly yours,

W G McGinnies

W. G. McGINNIES, Director

Enclosure

ANNUAL REPORT

of

THE ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION[1]

CALENDAR YEAR 1950

1/ Maintained by the U. S. Department of Agriculture, Forest Service, in cooperation with Colorado A & M College, Fort Collins, Colorado.

(Not for publication)

C O N T E N T S

RESEARCH FOR OUR NATION'S SECURITY

The Rocky Mountain Forest and Range Experiment Station has completed another year of research, aimed at the sound management and productive use of noncultivated lands in the Rocky Mountain Region.2/ In this five-state area, we are responsible for development of technical knowledge which can be used in the management of both publicly and privately owned forests and ranges. Whatever we can contribute to the increased productivity of these lands is reflected in national prosperity. Also, World War II has clearly demonstrated that the resources of these forests and ranges are the foundation of our security.

The past 12 months have brought us dangerously close to another struggle for survival. This time it promises to be a supreme test of our capacity to wage war. With an uneasy foreboding, our leaders have again paused to take stock of our natural resources. In agriculture, these are food and fiber and two of their essential ingredients, water and soil. In past crises we have drawn heavily on reserves of timber, on forage for production of beef, hides, and wool, and on the capacity of soil to grow crops. They have served us well. But no one can guarantee that supplies of these essentials under present-day management practices will meet our needs in future emergencies. We do know, however, that better management is possible. Moreover, it is absolutely necessary if we are to build greater strength for both peace and war.

In no part of this country is the unused potential greater than in the Rocky Mountain Region. Lack of knowledge in the techniques of resource management is a major reason and the result is manifested in two ways. We have failed to develop fully some resources which are available, and have been guilty of profligate overuse of others. Both practices are a detriment to long-run productive power. For example, in Colorado 270 billion board feet of timber are ready for use, but much of it is out of reach for our present logging methods and road-building techniques. In the same State, livestock are eking out 100 pounds of forage per acre from 4 million acres of pinyon-juniper range, but at the same time causing many tons of sediment to move into channels and reservoirs. A few thousand acres of well-managed pasture land would relieve this pressure which is causing permanent damage to watershed values. Further, some 80 percent of the water received in rain and snow is lost by evaporation and transpiration. We suspect that certain amounts of this lost water can be salvaged for productive use, but the methods are barely within our grasp.

2/ Rocky Mountain Region, as used hereinafter, refers to the area served by the Rocky Mountain Forest and Range Experiment Station and Region 2 of the Forest Service. It includes Colorado, Kansas, Nebraska, South Dakota, and Wyoming exclusive of a portion of the State west of the Continental Divide.

Our job at the Rocky Mountain Forest and Range Experiment Station is to solve these problems as rapidly as possible. The object of this report is to summarize the progress made in 1950 and to touch on whatever background is necessary for better understanding of current activities. Results have been arranged according to our three major fields of research--watershed, range, and timber management.

WHERE WE DO OUR RESEARCH

If water, grass, and trees behaved the same way in all parts of the Rocky Mountain area, our job of research would be greatly simplified. Needless to say, they don't in a region characterized by variations in elevation from 1,500 to over 14,000 feet, in precipitation from 5 to 40 inches, and in soils ranging from fine clays to coarse gravels. Vegetation is sensitive to even minor changes in environment. Good watershed management on one site may be poor for another. Grazing practices need alteration for every range type. Forest-management techniques require modification to meet changes in soil and other environmental factors. Engelmann spruce, for example, growing on the slopes of the Continental Divide requires different silvicultural practices than that grown on the Grand Mesa of Colorado. Obviously, it is not possible to conduct research on every variation of all problems confronting us in the region. The only alternative has been to select, for any intensive work, representative areas presenting the most acute needs for research.

At present, we are doing the most detailed work on our three major research projects at the following locations:

Watershed-Management Research

1. Manitou Experimental Forest in the Front Range.
2. Fraser Experimental Forest in the Continental Divide zone.
3. Western Slope of Colorado.

Range-Management Research

1. Central Plains Experimental Range in eastern Colorado short-grass.
2. Manitou Experimental Forest.
3. Western Slope of Colorado.
4. Wyoming.

Forest-Management Research

1. Fraser Experimental Forest.

Major problems of the region can be catalogued by broad physiographic provinces. Each area presents an opportunity for improved resource management.

The Front Range

Eastward from the Continental Divide in Colorado lies a relatively narrow rampart known as the Front Range. It is not primarily a water-yielding area, but vital water supplies must pass through it. All this flow is covered by water rights and even floodwaters have been appropriated for beneficial use. Every physical means for getting more water is being tried, including rain making and diversion by tunnels through the Continental Divide from the west.

The most important land-management job in the Front Range is to safeguard these vital water supplies. One of the major drainages flowing through the Front Range is the South Platte. Sediment dumped into this stream each year above Greeley, Colorado, causes an average of $2 million damage. The source is traceable mainly to overgrazing, irresponsible logging methods, and cultivation. Native vegetation provides only meager protection against these practices and special methods of resource management are necessary.

We are learning some of these management needs at Manitou Experimental Forest, located within the headwaters area of the South Platte River, 28 miles northwest of Colorado Springs. Since 1936, most of our Front Range research program has been concentrated within this representative area. Watershed-management research has been a major activity, closely correlated with range-management investigations.

Strong emphasis is being placed on the relation of cattle grazing intensities to erosion, runoff, forage production, and beef supplies. In addition, a series of watersheds is supplying information on surface runoff, ground-water behavior, and annual water yields in relation to the type of vegetative cover growing on them. We are also learning more about reseeding of abandoned cultivated fields and other depleted lands to control runoff and erosion, and build up their forage production.

Continental Divide

Two important resources, water and timber, are abundant in the high mountains of the Continental Divide. But this great barrier prevents the equitable distribution of water, and its rugged slopes make harvesting of the timber difficult. However, our research program is providing a partial answer to these problems. For example, our studies lead us to believe that water, which is so critically deficient on the eastern slope, may be increased by timber cutting. And some solutions to timber-harvesting problems are also being obtained from our timber-management research.

Most of this timber-watershed research is being done at Fraser Experimental Forest near Fraser, Colorado. Watershed and forest conditions typical of the high mountains above 9,000 feet elevation are well represented. The full range in the environmental limits of lodgepole pine and spruce-fir types is there. Harvest-cutting methods for both types are being studied in plots and also on one of a pair of experimental watersheds from which runoff records are obtained. So closely related are timber and water resources in this zone that the two management-research activities are carried on hand in hand.

The Western Slope

Westward, the great mass of the Continental Divide is flanked by a series of mountain ranges, mesas, and valleys known as the Western Slope. Resources of the area have national significance. Water from snowcapped peaks irrigate peach orchards in Colorado and orange groves in California. Under terms of the Colorado River Compact, a yearly minimum of 7.5 million acre-feet from the Upper Basin must be delivered to Lee's Ferry, Arizona. Seventy percent of this water comes from the Western Slope of Colorado.

Since 1946, the Rocky Mountain Station has been engaged in a research program on the Western Slope to seek out better watershed and range management. From our branch headquarters at Delta, Colorado, some of the more urgent problems are being investigated. Present studies deal mainly with the relation of cover type to erosion and forage production, methods of controlling noxious weeds, and reseeding on rangelands. Also, some small forested watersheds are being cut over to learn methods of promoting water yield without inducing siltation. All these activities are aimed at maintaining or increasing productivity of the land, and to make possible full development of natural resources.

The Central Plains

From the base of the Rockies eastward lies a wide expanse of short-grass vegetation stretching throughout eastern Colorado and Wyoming, and western Kansas and Nebraska. Conservation of snow and rain water is needed to meet the requirements of plant growth and prevent floods and erosion.

Our national security depends strongly on this area for production of meat, hides, and wool. Forage produced here feeds almost half of the breeding herds of cattle and sheep in the Rocky Mountain Region. By nature, it is best suited to this purpose. Yet, in two World Wars, the lure of high returns in wheat production has led to the unwise plowing of many thousand acres. During intervening periods much of this land has lain idle, productive of nothing but dust storms. Its original value as native range has been largely lost, but investment of money and care in reseeding may restore its value as rangeland.

We know that the remaining unplowed range can be made more productive because of results we have obtained from our grazing-management studies. These are being conducted at the Central Plains Experimental Range in northern Weld County, Colorado, 33 miles north of Greeley. Here we have a series of pastures forming part of the Briggsdale Unit of the Northeastern Colorado Land Utilization Project. The Federally owned lands in this unit, including the experimental area, are used by the Crow Valley Livestock Cooperative Association under paid permit from the U. S. Department of Agriculture. Individuals in this association own the cattle used to graze the experimental pastures. Rocky Mountain Station personnel manage the grazing use on the experimental pastures and the remainder of the project is under the supervision of the Soil Conservation Service.

Wyoming

Like Colorado, Wyoming's most valuable contribution to the national wealth is water. It supplies flow for the far-flung drainage systems of the Colorado, Columbia, and Missouri Rivers. In an average year, the State supplies 15 million acre-feet, 80 percent of which flows off to other states. This water also carries away large quantities of soil. The Yellowstone River, for example, transports 25,000 acre-feet of silt per year. This is 93 percent of the amount measured in the Missouri River 37 miles below the mouth of the Yellowstone, and a quarter of the amount carried by the Missouri past Kansas City.

The Rocky Mountain Station is responsible for watershed-, range-, and forest-management research on the east side of the Continental Divide in Wyoming. Work in all three activities is urgently needed. Present studies deal only with the reseeding and brush-control phases of the over-all problem of rangeland management. In cooperation with the Bureau of Land Management, the Soil Conservation Service, and the University of Wyoming, we are doing work on eradication of competitive vegetation, and reseeding of raw, eroding sites.

South Dakota, Nebraska, and Kansas

Water, range, and forest resources in this tri-State area present many problems yet to be included in the Rocky Mountain Station's research program. Such a program is needed to enable the area to make its best contribution to river-basin development in the West.

On the uncultivated lands, grass and livestock production can be increased by improving deteriorated ranges through management or reseeding. There is also a job to be done in watershed management. We need to know the effect of grazing use on conservation of surface and ground-water supplies, and the kind of range cover best suited for reduction of erosion, siltation, and flash flooding.

South Dakota has 1-3/4 million acres of commercial forest land supporting 3 billion board feet of timber. Most of it is ponderosa pine growing in the Black Hills. Present rate of growth, estimated at 35 million board feet annually, does not reflect the true potential of the area. Management has been based on experience and results elsewhere in the ponderosa pine type. At a time when this country desperately needs more wood production, generalizations from other regions no longer suffice a guide to cutting practices in the Black Hills. Research is sorely needed to provide a sound basis for intensive forest management. The Rocky Mountain Station has been able to contribute only in a small way by developing volume and yield tables for Forest Service use in timber sales.

In other portions of the three states, shelterbelts and farm woodlots have suffered from lack of research. In the mid-thirties, when a major portion of the present shelterbelts were established, some research was directed toward better methods of propagation and maintenance. Research should be reactivated and stepped up to include farm-woodlot management.

WATERSHED-MANAGEMENT RESEARCH

Watershed management is a relatively new concept. It means more than mere protection as once thought; a broader interpretation has developed. As stated in a recent report by the President's Water Resources Policy Commission, "Watershed management is the foundation of a conservation and development program for soil and water resources. It is designed to maintain the productivity of these resources at not less than their present levels and help raise those levels to meet increasing requirements. It is based on a recognition that land and water resources are interdependent and must be used so that each reinforces the productivity of the other."

In management of noncultivated land, productivity of water and soil is measured in terms of forage and timber. But water has the added duty of supplying the needs of irrigated farms, municipalities, and industries. Watershed management, therefore, entails broad responsibilities. Maximum production of forage and timber must always be tempered by the needs for maximum production of usable water--to be usable it should be available when needed, free of pollution and sediment.

There is a point of balance in every land type where this ideal can be reached. The problem is to find it. It is easy to tip the balance toward overuse of forage or overcutting of timber with resulting erosion of the watershed and deterioration of water values. It is also possible to swing too far to the conservative side with a loss of production. In some cases complete protection is necessary, but more often some use of forage or timber is compatible with the goal of maximum supplies of usable water.

The philosophy of multiple use, a basic feature in Forest Service land-use policy, is exemplified by this concept of watershed management. Likewise, it is fundamental in our program of research.

At present, our watershed-management research program is under way at three branch stations:

1. Manitou Experimental Forest.
2. Fraser Experimental Forest.
3. Western Slope of Colorado.

In the following discussion of research results, the material has been organized by the major problems which concern us:

1. Stream flow and water yield.
2. Surface runoff and erosion.

Some watersheds may supply more water

In 1938, the Rocky Mountain Station began a series of experiments at Fraser Experimental Forest designed to show the relation of water yields to timber cutting in lodgepole pine and Engelmann spruce. The Continental Divide zone is a logical place to undertake these studies because of its characteristics favoring water yield. Most of the precipitation falls as snow which melts at a relatively slow rate in the spring. Ample vegetative cover and porous soil conditions cause almost all of the released water to enter the ground immediately from which it appears later as regulated stream flow.

The first step was a study of twenty 5-acre plots in mature lodgepole pine. All measurable components of the water cycle were observed under four intensities of cutting and compared with uncut plots. The study showed that it is possible to obtain savings up to 31 percent in water available for stream flow by removal of all salable timber. Lesser savings were measured in intermediate cutting treatments. Similar results occurred when the study was extended to thinning of young lodgepole pine and harvest cutting of Engelmann spruce. In all cases, tree cutting allowed more snow to be stored on the ground by reducing the screening effect of tree crowns. We have assumed that added runoff occurs as a result of this increase in the snow-pack.

Experimental watersheds will give the answer

Data from the plots haven't given the complete story because it has not been possible to measure changes in stream flow--the end product of the cutting treatments. While this preliminary investigation was under way, preparations were made for a watershed study designed to give us a more complete answer. In 1939, a stream-gaging station was installed in Fool Creek, a forest-covered watershed located near the lodgepole pine harvest-cutting plots in Fraser Experimental Forest. Stream-flow records at the gaging station and precipitation measurements from the 710-acre area above it have been taken since that time in an effort to evaluate undisturbed conditions as completely as possible.

The 12 years so far devoted to this pretreatment phase have been necessary to provide a means of assessing effects of the cutting treatment when it is applied. As an added safeguard, we have also included in the study an adjacent check watershed known as East St. Louis Creek. A gaging station was installed in 1943, and records of runoff and precipitation have been kept concurrently with those of Fool Creek since that time. A basic relationship between the normal flow of the two streams has now been established and tested. Any significant alteration of flow in Fool Creek as a result of treatment can be evaluated because East St. Louis Creek will continue to flow from an undisturbed watershed.

Completion of the preliminary phase has now opened the way for timber cutting in Fool Creek. The time is opportune because of the nation's current need for wood products. Approximately 6.5 million board feet of commercially valuable timber are available for cutting.

The volume is divided about equally between lodgepole pine and Engelmann spruce. We propose to cut almost half of this timber by alternate strips in the near future. Timber in the uncut strips will be harvested when the results of the initial removal are known. In 1950, the necessary 4.5 miles of main access road were virtually completed and nine feeder roads were surveyed.

There will be a number of important byproducts from the Fool Creek watershed study in addition to the main effects of timber cutting on water yields. At present, we plan to postpone cutting for an estimated period of 2 years to measure the separate effect of the roads on runoff and erosion. We also expect to obtain valuable information on construction and maintenance of logging roads; the silvicultural desirability of strip cutting in high-altitude water-yielding forests; and the relation of such cutting to local climate, soil moisture, and wind movement.

Water-yield tests needed in other localities

The results from Fool Creek will be considerably strengthened if they are borne out by trials in other high-yield watersheds. The ideal situation calls for a series of paired drainages which completely sample the range of conditions found in the Continental Divide zone.

This ideal has not been possible but, in an effort to approach it, we have established three experimental drainages in the headwaters of Eagle River above Minturn, Colorado. These are the Red Sandstone watersheds, with areas varying from 1/2 to 2 square miles. They are also in the spruce-fir and lodgepole pine type, all three ranging from 10,000 to about 12,000 feet in elevation.

Records similar to those kept on Fool Creek and East St. Louis Creek were begun in October 1947. Stream flow through sharp-crested rectangular weirs has been automatically recorded on charts during the months of April to October. Early-spring and late-fall measurements have been seriously affected by ice, and in 1950 some attempts were made to overcome the difficulty so that reliable records can be extended over a longer period. It is highly desirable to have a measure of winter flow if procedures can be worked out. An index of winter snow accumulation is obtained by a Sacramento snow-storage gage.

One of the three experimental watersheds is being logged as a part of a Forest Service timber sale. When the gaging station was established in 1947, timber cutting had covered 7 percent of the watershed and, by the end of 1950, about 35 percent. Some surface runoff from melting snow on the logged-over area was observed during the spring break-up of 1950. Most of this occurred on logging roads, but smaller amounts were noted on skid trails. Whatever effect this has had on water yields has not been sufficiently great to detect at the gaging station.

Cooperation provides information on runoff

Since 1947 the Forest Service and Bureau of Reclamation have joined forces in snow-melt investigations at Fraser Experimental Forest to find out what physical factors influence runoff from snow and how well they can be correlated. For the Bureau of Reclamation, the study has very practical implications in the prediction of water supply for firm power and fluctuations in water level that materially affect reservoir operation. In addition, it provides much-needed data for flood-design studies.

The program has dovetailed nicely with our interest in the relation of cover to runoff. Physical factors such as local wind movement, temperature, humidity, and evaporation are associated with tree cover and help explain the effect of timber removal on water yields.

The techniques developed in these cooperative investigations are now being employed in Fool Creek watershed to increase breadth and value of the study. For example, this year, by virtue of the cooperative program, we have obtained some necessary equipment for making a continuous record of wind movement and direction at various levels in the undisturbed forest cover. We intend to follow up with comparisons between cut and uncut strips following timber harvesting. Not only will these measurements provide data on snow accumulation and melt, but also will tell us the direction and intensity of winds which cause blow-down.

The 1950 season marked the completion of field work required by the Bureau of Reclamation in this joint study. During the snow-melt period the following records were kept:

1. Continuous records of relative humidity and temperature at three selected sites on Fraser Experimental Forest.
2. Wind movement at 50-foot, 25-foot, and ground levels in adjoining sites, one forested and the other open (West St. Louis Creek climatic station).
3. Winter and spring precipitation storage at five widely separated sites on the experimental forest.
4. Rates of snow disappearance for all aspects and elevations within the 32.8 square miles of the experimental forest above the main St. Louis Creek gaging station.

All data are being correlated with the flow at the St. Louis Creek gaging station, as has been done in previous years, to strengthen their indicated relationships with runoff. Our more detailed measurements on Fool Creek, which is tributary to this larger system, have proven a valuable adjunct to the study.

Snow-disappearance studies aid in forecasting rate of runoff

There has been a long-standing need for methods to follow the progress of snow-melt over large watersheds with wide ranges of elevation, exposure, aspect, and cover condition. In 1950 we undertook such a study

to develop methods for later use in Fool Creek and also to round out the cooperative snow investigation with the Bureau of Reclamation. Methods involved the periodic mapping and photographing of snow cover on:

1. The entire experimental forest above main St. Louis Creek stream gage.
2. Adjacent north and south slopes in detail.
3. West St. Louis Creek climatic-station clearing.

St. Louis Creek watershed.--Ocular estimates of the percent of the watershed area covered with snow were made weekly for each subdrainage from three observation points. The areas covered with snow were then drawn on maps, planimetered, weighted according to percent cover, and an average percent snow cover determined for that day. A detailed study of these maps will be made in order to correlate snow disappearance with climate and topography.

The snow-melt season in St. Louis Creek watershed lasts about $3\frac{1}{2}$ months, from early April to late July.

1. The first snow disappeared about 15 days before any stream rise was noted.
2. The time of most rapid snow disappearance coincided with the time of peak stream flow (June 16).
3. The last snow disappeared about 30 days before stream flow dropped to the summer level.
4. The snow-melt curve (percent snow cover plotted against time) coincided almost exactly with a stream-flow curve (remaining percent of the total volume of stream flow for the period April 1 to July 12, plotted against time).

Percent of snow cover and stream flow in cubic feet per second for corresponding dates in the St. Louis Creek watershed are shown in table 1.

Table 1.--Relation of snow-cover disappearance to rate of stream flow in St. Louis Creek watershed, Fraser Experimental Forest. 1950.

Date		Snow cover	Stream flow
1950		Percent area	Cu.ft./sec.
April	1	97.7	9
	4	100.0	9
	14	94.9	12
	27	93.5	12
May	9	91.7	20
	12	89.2	23
	19	90.0	42
June	6	70.1	135
	13	49.2	212
	20	36.3	200
	27	18.7	145
July	3	7.2	113
	12	2.1	74

North-south slopes.--Studies were made on adjacent north- and south-facing slopes of West St. Louis Creek to determine the relative rates of snow disappearance. Two snow courses and four precipitation gages were measured weekly on each slope. Relative rates of disappearance corrected for precipitation are shown in table 2. Snow courses on the south slope were bare of snow about a month ahead of those on the north slopes.

Table 2.--Relative rates of snow disappearance on north and south slopes. All data corrected for precipitation. Fraser Experimental Forest. 1950.

Date	Snow disappearance in inches of water equivalent	
	North slope	South slope
1950	inches	inches
April 5 - 12	0.86	2.78
12 - 19	1/ ----	2.15
19 - 26	1.51	4.39
26 - May 3	1.56	2.75
May 3 - 10	1.33	1.59
10 - 17	2.01	1.30
17 - 24	3.28	----
24 - 31	1.35	----
31 - June 7	5.56	----
June 7 - 14	2.30	----
14 - 22	0.88	----

1/ No measurable loss.

West St. Louis Creek climatic station.--Five detailed observations were made during the period of snow disappearance in the climatic-station clearing (May 10-31, 1950). On each occasion, the snow cover was mapped in detail by eye from the top of the wind tower. During the same period three snow courses within the clearing were measured weekly and continuous records were kept of temperature, humidity, and wind movement in the clearing.

After all the snow had left, a topographic map of the area was made, using 1-foot contour intervals. From the data obtained in this study, correlations will be made between snow disappearance and local conditions of climate and topography.

Soil-moisture study.--Twenty-three soil pits were dug during the snow-disappearance period. The water content of the soil at different levels was estimated and most pits were revisited to record changes in the soil moisture. About half the pits were dug under snow. Most of these revealed a layer of soil carrying free water at an average depth of 3 feet. Water-bearing layers were about 6 inches thick.

In two of the pits dug through snow in late April a zone of dry soil was found about 1½ feet below the ground surface. Wet soil occurred both above and below it. Subsequent visits in early May, however, indicated that the snow-melt water had penetrated the dry layer.

Alpine soil-ice provides late flow

Ice and frozen soils are found throughout the summer in the high alpine country and, as the ice melts, water is contributed to stream flow. The flows emerge as springs in the vicinity of timber line or at some little distance below. Water temperature of vigorously flowing seeps ranged between 34° and 38° F.; slow-flowing springs and seeps have higher temperatures.

A mat of vegetation insulates the soil and prevents rapid melting of ice. This organic or peaty layer is thickest and most effective in marshy or swampy areas. In one such swamp in the Mosquito Range, the frozen soil-ice mixture was found just 7 inches below the surface on August 29, 1950. In adjacent bare-soil areas of the same swamp the frozen mixture occurred at 40 inches depth. These conditions existed despite the fact that this locality was fully exposed to the sun. It appears that the high alpine lands may be more important to the irrigation farmer than has been previously suspected. They are deserving of additional study and a more prominent place in land management than has been given them.

Fall soil moisture affects stream flow during the following spring

Almost all the water in high mountain streams is delivered through the soil. Moisture used by lodgepole pine and Engelmann spruce during the summer must be replaced before the soil reservoir will again feed water to the streams. Amounts of water these trees take from the soil reservoir and the depth of their moisture-feeding zone have never been precisely measured. A start was made on this problem in 1950 at the Fraser Experimental Forest and, while the study is incomplete, the results may indicate what can be expected from a full-scale experiment.

The logging road under construction in the Fool Creek watershed exposed many deep cuts where the soils could be studied to considerable depths. The summer had been very dry, and the trees had probably extracted all possible moisture from the soil. Using due sampling precautions, soil samples were taken from five deep profiles at intervals from the surface down to depths of 4 to 9 feet. The samples were taken on September 21 and 22. In the previous 10 days, the summer drought had been broken by 1.4 inches of rain, 0.48 inch of which fell in the 2 days preceding sampling. This moisture brought the surface soil to field capacity but left the deeper layers very dry. Moisture percentages obtained were based on oven-dry weight of the whole soil sample which included gravel.

In all profiles, the tree roots extracted the moisture nearly uniformly to a depth of 36 inches. Soil moisture showed a gradual increase between 36 and 60 inches, and the data indicated that extraction of moisture by roots had nearly ceased or was unimportant below a 60-inch depth.

The average moisture percents for the newly wetted surface, the dry subsoil, and the moist deeper soil layers are shown below.

	Average moisture (percent)	Range in moisture (percent)
Surface soil	10.2	6.6 to 16.8
Subsoil (to 36 inches)	7.3	4.4 to 13.0
Deep soil layers(below 36 inches)	11.7	5.8 to 20.5

Values are averages based on dry weight of all samples within the depths indicated. The range in moisture percent can be explained by the amount of gravel in each sample--the more gravel the less moisture the soil will hold. Average moisture percent for the subsoil was 7.3, but four of the five profiles had one or more points that fell between 4.4 and 6.9 percent in the subsoil, with an average value of 5.6 percent. It is believed that this 5.6 percent value gives a truer measure of subsoil moisture after trees have extracted all they can get.

Moisture-deficit at the time of sampling can be estimated with a fair degree of accuracy. If it can be assumed that surface and deep soil layers were at field capacity, the average moisture percent of the two, 10.9 percent, can be used as an estimate of the percent of water held by the soil in this condition. Also, since the trees had drawn upon the water in the subsoil all summer it is likely that a moisture content of 5.6 percent in this zone approaches the wilting point. The difference between this figure and the 10.9 percent of field capacity suggests that the soil had a moisture-deficit of 5.3 percent to a depth of 36 inches before fall rains moistened the surface again. In earlier studies we found that soils in the vicinity have an average density (volume weight) of 1.57. From this figure we can calculate the indicated deficit for the upper 36 inches of the soil mantle at about 3 acre-inches of water. In exceptionally dry seasons when trees have extracted all the moisture possible and fall rains do not relieve the dry condition, about 3 acre-inches of snow water are required from the spring melt to satisfy soil deficiency before streams can begin their seasonal rise.

There are some very practical implications here. It has been suggested, for example, that a good part of the errors common in predictions of water supplies from snow are caused by fluctuations in fall soil-moisture conditions. If fall conditions varied within a range of only 10 percent in this 36-inch zone, the difference in soil-moisture demands during the following spring would be 0.025 acre-foot per acre. For a million-acre watershed the possible error, then, is 25,000 acre-feet.

Front Range watersheds have different characteristics

Turning now from the Continental Divide zone to the Front Range, we find much different runoff conditions. These are best exemplified by a 4,800-acre watershed at Manitou Experimental Forest known as Missouri Gulch. Stream-flow records were started here in 1940 along with a relatively intensive sampling of precipitation. A series of rain gages supply information on the amount and areal distribution of precipitation as well

as the time of occurrence and intensity of each storm. Two ground-water wells provide a continuous record of the fluctuation in levels of the water table.

From 11 years of record, it has been possible to develop a pattern of behavior which is characteristic of Front Range streams. Water yields, for example, are much smaller and less reliable than those from the Continental Divide. Chief reason is the relatively low amounts of winter and spring precipitation which all our watershed studies have shown to be the main source of water yield. In the Front Range, the major share of the precipitation falls in the summer period. In most cases it comes from thunder storms producing intense showers. Often, these merely wet the soil surface and never appear as stream flow. In rarer instances a series of large storms of the convection type will occur over short periods, as in 1945, and completely fill the soil storage capacity resulting in flood conditions. In 1950 total stream discharge was the lowest for the period of record, not only because the precipitation was 5 inches below the normal of 17 inches, but also because very little of it occurred in winter and spring.

Soil moisture is strongly influenced by exposure

In 1950 we made an intensive study in three 1-acre experimental watersheds to follow the trend of soil moisture under a variety of conditions through the summer. The watersheds are part of a series at Manitou Experimental Forest on which we are investigating the relation of vegetative changes to runoff and erosion. Two of the three watersheds used in this study have had all the ponderosa pine removed and the third remains in its original condition.

Samples were taken with a soil tube for a period of 9 weeks during July, August, and early September. Ten randomly chosen sample points were selected within each watershed every week. Each succeeding week new locations were randomly selected. Depth of measurement was 18 inches from which two subsamples of 0-6 inches and 6-18 inches were obtained. Added information for each sampling point was also obtained, including:

1. Compass direction of exposure.
2. Slope of ground in percent.
3. Number of live plants in a square foot centered over the sample point.
4. Estimated percent of litter cover in the same square-foot area.

The results showed a significant difference in moisture content between watersheds for the entire 9-week period. In addition, they pointed to a very strong correlation between soil moisture and two factors: direction of exposure and litter density on the ground surface. The relationship with exposure held true for both the 0-6-inch and 6-18-inch zones, but litter density showed a weakened relation to soil moisture in the 6-18-inch zone. The number of live plants per square foot was weakly correlated with soil moisture in the upper zone, and showed no influence at all on moisture in the lower zones. Litter density

had a positive relationship with soil moisture, indicating that it protects soil from drying. Live plants had the opposite effect or a negative correlation. In other words, the transpiration draft of live plants tends to dry the soil, more than offsetting whatever effect their shade may have in reducing evaporation.

SURFACE RUNOFF AND EROSION

It is quite common in the Front Range for water to run off the land surface in a flashy type of flow, bringing with it heavy loads of sediment and leaving depleted eroded sites. Two factors cause this. One is the high intensities often reached in rain storms, and the other is inadequacy of vegetative cover. Man's use of the land, of course, greatly modifies and often deteriorates the protective influence of vegetation. Aside from these modifications, wide variations will exist in natural protective qualities. This has been borne out by some observations we made on three cover types growing on granitic-derived soils in Missouri Gulch. This watershed is typical of many acres of land in the Front Range, but in recent years has not suffered the usual intensity of disturbance by grazing and other uses.

Tests were made during the spring of 1950 using an infiltrometer which provides information on infiltration and erosion rates.3/ Vegetative types examined were aspen, ponderosa pine with an understory of grass, and the mountain-brush type consisting mostly of mountain mahogany. Aspen was found on the north and east exposures, while the other two types occurred on south and west exposures. Plots were located at random within the three types on a variety of slope grades. All of the Missouri Gulch drainage is conservatively grazed by livestock. Some 50 years ago a portion was logged and burned, but no recent logging has been permitted.

Aspen stands provide superior watershed protection

Results of this study show that the aspen type, by virtue of its high infiltration rate and low erosion rate, provides superior watershed protection. The ponderosa pine type, although having a moderately high infiltration rate, has also an accelerated erosion rate amounting to 7 cubic feet of soil per acre per inch of surface runoff.4/ This rate is

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3/ The Rocky Mountain infiltrometer, type FA. From 4.5 to 5.5 inches of water per hour are applied from a height of 6.5 feet for a 50-minute period on a 2.5 square-foot plot. The soil of the plot is brought to field moisture capacity 24 hours prior to the test run. Infiltration rate is the average rate for the last 20 minutes of the 50-minute run and is expressed in inches per hour. Erosion rate is the total oven-dry soil material moved off the plot divided by the total inches of runoff water causing the movement of soil during the 50-minute run. It is expressed in pounds per acre per inch of surface runoff.

4/ From limited volume-weight studies, a cubic foot of soil in the Missouri Gulch drainage weighs about 78 pounds.

not as serious as that found on the mountain-brush type where the erosion rate amounted to 30 cubic feet of soil per acre per inch of surface runoff. Infiltration rates of the mountain-brush type are moderately high, but the runoff which does occur moves large quantities of soil. Unlike the other two types, the ground surface is not well protected by plants or litter, often consisting only of a bare gravel pavement from 1 to 2 inches thick. It is capable of absorbing water rapidly due to its gravelly nature, but is highly erodible even when small surface flows of water occur. Our tests show that among the cover types we studied, mountain-brush type provides the poorest watershed protection, ponderosa pine-grass type is intermediate, and aspen is the best.

These results are summarized in table 3 which gives average infiltration and erosion rates for the three vegetative types:

Table 3.--Infiltration and erosion rates for three cover types in Missouri Gulch watershed. Manitou Experimental Forest. 1950.

Vegetation type	No. of plots	Range in slope	Infiltration rate (f_c)	Erosion rate 1/
		percent	in./hr.	
Aspen	12	9 - 41	4.30	2/ 16
Ponderosa pine	10	9 - 39	3.14	557
Mountain brush	10	24 - 56	3.22	2,356

1/ Pounds per acre per inch of surface runoff.
2/ Only 2 of 12 plots yielded erosion.

The more the bare area, the greater the erosion rate

When the soil surface of granitic-derived soils is devoid of live vegetation or litter it is susceptible to water erosion. More particularly is this true on slopes where a sparse vegetative cover occurs and where the force of rain is broken only by a gravel pavement. A significant correlation was obtained between the percent of bare area and the erosion rate measured by infiltrometer plots randomly located in the three vegetation types. This comparison provides an erosion-rate index for granitic-derived soils regardless of vegetation types. Expected relation between erosion rate and percent of bare area, calculated from data in this study is:

Bare area (percent)	Erosion rate (Lbs./A./In. surface runoff)
0	236
10	490
20	744
30	998
40	1,252
50	1,505
60	1,759
70	2,013
80	2,267
90	2,521
100	2,774

Instability of the granitic-derived soils is illustrated by the expected rate of erosion (236 pounds per acre per inch of surface runoff) when the soil surface is completely covered by live vegetation or litter. It amounts to some 3 cubic feet of soil moved per acre. Even with half of the soil surface covered, the erosion rate is high--over six times that of complete cover. On the granitic-derived soils, particularly the steep slopes, it is important to maintain as much live vegetation or litter on the soil surface as possible in order to reduce surface soil movement to a minimum.

Gravels on the soil surface constitute the bulk of materials eroded

Commonly, the soil surface of the granitic-derived soils is covered with a gravel or erosion pavement. This pavement is composed of the coarse gravels remaining after the fine particles have been washed down through them or carried away completely. These gravels vary from the size of a small pea to egg-sized stones. On steep slopes the beating of raindrops, together with the movement of surface water, causes the gravels to creep downslope, particularly where the soil surface is bare. Soil moved on all of the infiltrometer plots was analyzed as to particle size and summarized as follows:

Soil particles	Average proportion by weight
	(percent)
Coarse and fine gravel (1 mm. or more)	55
Coarse sand (0.5 to 1 mm.)	17
Medium sand (0.2 to 0.5 mm.)	19
Fine sand, silt, clay (0.2 mm. or less)	9
	100

The "fines" (fine sand, silt, and clay) are located underneath the gravel pavement and are thereby protected from the beating action of the infiltrometer raindrops. Once the gravels are moved by the rain or the surface movement of the water, the fines are washed out. It would appear that, although a gravel pavement does protect the soil surface to some extent, it is not as effective as live vegetation or litter. Gravel can be moved by water subjecting the soil underneath to washing. On the contrary, plants are less subject to movement and tend to hold soil particles in place.

Aspen and bunchgrass provide good watershed protection on the Western Slope

Infiltration tests on the Western Slope tell a similar story. In 1950 we sampled 25 separate sites, each representing a distinct range subtype on four national forests. On each forest, as shown below, we selected three to nine sites having soils of similar origin and sampled each one with six randomly selected infiltration-erosion plots.

National forest	General location	Soil origin	No. sites
Gunnison	Black Mesa	Acid volcanic	9
White River	White River Plateau	Mixed sedimentary	7
Grand Mesa	Muddy Drainage	Wasatch shale	6
Routt	California Park	Mixed (mainly sed.)	3

The widest range of distinctive subtypes in both good and poor condition was found on Black Mesa, in both open parks and aspen woodland types. Nine sites were selected, including seven which were representative of recognizable subtypes and conditions in the open parks. Of the remaining two sites, one is representative of poor aspen and the other of depleted aspen (table 4). Data from California Park, White River Plateau, and Muddy Drainage are each based on fewer samples. For that reason, the results from Black Mesa are elaborated more fully than the others in the following discussion.

Table 4.--Infiltration and runoff for selected range-watershed subtypes and conditions on Black Mesa. 1950.

Subtype 1/	Soil texture	Average slope	Average infiltration rate	Surface runoff from applied rainfall
		percent	in./hr.	percent
Open parks				
Good bunchgrass	Sandy loam	15	4.8	3
Lush weed	Loam	13	4.5	8
Poor bunchgrass	Loam	18	4.2	9
Bromegrass-weed	Loam	12	4.2	13
Needlegrass	Gravelly loam	16	3.6	24
Poor weed	Clay loam	15	2.5	42
Bluegrass	Heavy loam	10	2.3	48
Aspen woodland				
Poor aspen	Gravelly loam	22	4.8	2
Depleted aspen	Loam	27	3.9	25

1/ Composition of subtypes:

Good bunchgrass - Thurber fescue (80 percent of the grass cover) sheep fescue, Letterman needlegrass, bluegrass, sedges, geranium, fleabane, yarrow.

Lush weed - Cinquefoil, wyethia, geranium, fleabane. Comparatively little grass consisting mainly of mountain brome, sheep fescue, Letterman needlegrass.

Poor bunchgrass - Thurber fescue (60 percent of grass cover), dandelion, fleabane, yarrow, geranium, aspen peavine.

Bromegrass-weed - Mountain brome (70 percent of grass cover), sheep fescue, Letterman needlegrass, geranium, fleabane, aspen peavine.

Needlegrass - Letterman needlegrass and sheep fescue (80 percent of grass cover), dandelion, geranium, fleabane, yarrow.

Poor weed - Mainly dandelion and sneezeweed. Scant grass consisting of needlegrass, bromes, prairie junegrass.

Bluegrass - Bluegrass (88 percent of grass cover), dandelion (50 percent of weed cover), slimstem cinquefoil, yarrow.

Aspen woodland - Understory of sedges, dandelion, strawberry, aspen peavine.

Good bunchgrass and poor aspen proved to be good watershed cover. Both had average infiltration rates of at least 4.8 inches per hour. Aspen stands on Black Mesa present watershed problems only when seriously depleted. Even under these conditions, infiltration approached the rate of 4 inches per hour.

Three other subtypes on Black Mesa were almost as good. Lush weed, bromegrass-weed, and poor bunchgrass showed somewhat less capacity to absorb water, but the difference could have been chance occurrence. On Black Mesa, all sites with infiltration rates in excess of 4 inches per hour may be considered to have adequate protection. Less than 15-percent runoff can be expected to occur from high-intensity storms. Needlegrass subtype is intermediate in capacity to absorb water; poor weed and bluegrass, the lowest. These last two absorbed only slightly more than half the total rain applied and apparently are sources of concentrated runoff during severe storms.

Poor weed subtype -- poor watershed protection

Poor weed subtype appears to offer the most serious erosion problem on Black Mesa. Soil movement at the rate of nearly 2 tons per acre for each inch of surface runoff means critical watershed conditions prevail. If 200 pounds of eroded material per acre per inch of surface runoff is an allowable maximum for adequate watershed management, good bunchgrass, bluegrass, and poor aspen subtypes on Black Mesa provide acceptable cover. More complete sampling may prove that lush weed and depleted aspen also provide average conditions which approach acceptable standards for erosion control.

The range-watershed studies on Black Mesa have shown a relation between erosion and bare area similar to that brought out in studies at the Manitou Experimental Forest (see page 17). The relationship for Black Mesa is shown in table 5.

Table 5.--Relation of litter and bare area to soil movement on Black Mesa. 1950.

Subtype	Litter cover1/	Bare area1/	Erosion rate2/	Total soil loss from applied rain3/
	Percent	Percent		Lbs./A.
Open parks				
Good bunchgrass	56	12	57	10
Bluegrass	47	21	181	251
Lush weed	28	31	304	102
Bromegrass-weed	48	21	723	156
Needlegrass	34	37	764	552
Poor bunchgrass	47	21	1,006	479
Poor weed	12	62	3,372	5,737
Aspen woodland				
Poor aspen	61	13	0	0
Depleted aspen	88	4	219	171

1/ Estimates obtained by sampling each site with 25 plots.
2/ Pounds per acre per inch of surface runoff.
3/ Rainfall was applied at the average rate of 5 inches per hour for 50 minutes.

Bluegrass produces high surface runoff but erosion is intermediate

Bluegrass is an enigma in range and watershed management. Many observers have doubted its value in watershed protection in spite of an appearance of a good cover. Data from Black Mesa are by no means conclusive, but they do show that bluegrass has both good and bad features. Surface runoff from bluegrass sites was the highest of all subtypes and conditions tested, but rates of erosion in pounds per acre per inch of surface runoff were third lowest. However, since relatively large amounts of water flow over the surface during a given storm, the total quantity of soil transported is intermediate in amount. High surface runoff appears to be the worst feature of bluegrass. While it offers moderate protection to its own site, it tends to shed destructive flows of water to downstream sites with poorer protection.

It is further evidence that erosion is strongly related to bare area. Bluegrass forms a rather dense mat over the soil surface and while it has poor absorptive capacities, it provides relatively good protection against soil movement. If the same low infiltration rates prevailed on poorly covered sites, erosion would increase manyfold.

Bunchgrass plots continue to show effects of grazing

For 10 years we have measured runoff and erosion resulting from grazing on six permanent 1/100-acre bunchgrass plots located at Manitou Experimental Forest. Heavy grazing, which has been regulated on two plots so as to remove two-thirds of each year's herbage production, has consistently resulted in increased rates of runoff and erosion. The comparison was made with two ungrazed plots and two which were moderately grazed--one-third of the annual herbage production removed. Surface runoff increased in proportion to intensity of grazing, but erosion has not. It has remained substantially the same for both ungrazed and moderately grazed plots, but jumped to more than twice this amount for heavy grazing. The average erosion-producing storm has removed 56, 60, and 128 pounds of air-dry material from ungrazed, moderately grazed, and heavily grazed plots, respectively.

Permanent plots and watersheds show effect of litter removal

At Manitou Experimental Forest, we have two studies which further substantiate our observation on the relation of bare area to erosion. One of these involves two batteries of 1/100-acre plots with a dense cover of young ponderosa pine. All plots face north with a slope of 17 percent. In 1941, the ground surface of one battery was cleared of all litter and debris, exposing mineral soil and highly decomposed organic matter. Within a month we had erosion from a single storm running as high as 4 tons per acre while the untreated battery continued to produce well under 200 pounds per acre for even the maximum storm. As years progress and no further disturbance has been allowed on the treated plots, litter cover is returning to normal and erosion has dropped back to the same rate as that on the check plots.

The second of these studies is being conducted on six small watersheds averaging about 1 acre in area. One of these watersheds in particular brings out the value of adequate cover. In the summer of 1948 we cut down all the ponderosa pine, leaving only a few remnants of aspen with the intention of encouraging a complete cover of that species. The pine logs were removed by hand and the slash was scattered and burned during the following winter. There was no disturbance to the soil from trucks or other machinery because we wanted to get the isolated effect of cover removal and burning. In the following summer the air-dry weight of eroded material produced from the maximum storm of 1 inch was 2,857 pounds--better than a ton per acre and just double anything we had received from the watershed in the previous 10 years of record. In the summer of 1950, the largest storm, $1\frac{1}{2}$ inches, produced 1,768 pounds air-dry eroded material. This was still greater than any amount received before cutting and burning, but reflects an increasingly protective influence of weeds which have sprung up since the fire.

Erosion hazard is low if forest-soil condition is undisturbed

In the foregoing examples of erosion on forested areas one thing is evident: the original forest-soil characteristics have been seriously altered. In both cases mineral soil had been exposed by fire, or a treatment simulating fire, on almost 100 percent of the area.

We have evidence, though, particularly in the Continental Divide zone, that logging can be done without seriously damaging the protective qualities of the forest-soil complex. In 1939, 20 plots at Fraser Experimental Forest were cut for experimental purposes and the logs removed by horse skidding and truck haul (see page 8). Very little damage was done to the understory consisting primarily of buffaloberry, and the litter was disturbed only by an occasional skid trail. No special efforts were made to alter normal logging practices. In 12 years since logging, the only signs of erosion are in the truck roads, where water has collected in the wheel ruts on steep pitches, and very slightly in some of the skid trails.

We have observed a similar situation as a result of present logging on one of the Red Sandstone experimental watersheds in the headwaters of Eagle River. Surface runoff occurred from melting snow on logged-over areas during both the 1949 and 1950 spring break-up. Most surface runoff originated on logging roads, but smaller amounts were yielded from skid trails. In all instances surface runoff water was clear of suspended sediment, but slight movement of heavier materials along ground surface was noted. None of these materials has reached the gaging station; stream flow since the experiment began in 1947 has been clear and free of sediment.

Wanted--a cheap, erosion-proof logging road

This country's defense-production program is going to place far greater demands on forest products of the region. It will be possible only with a greatly expanded program for building access roads into our timber supplies. It was estimated recently that adequate development and management of forest resources in the Rocky Mountain empire would require an average of 6 to 8 miles of road per square mile.

We plan to study the influence of an intensive network of roads on runoff and erosion in Fool Creek watershed at Fraser Experimental Forest. Records at the gaging station will provide an estimate of possible changes in stream flow and these will be supplemented by small catchments along sample road sections to detect the most likely sources of alteration in flow.

The most important effect will no doubt be in quantities of soil movement from erosion. To measure this, we have just completed construction of a large debris basin in the main channel of Fool Creek immediately below the stream gage. Sources of erosion will be carefully watched in an effort to determine practices to avoid in road building. It will be necessary for some feeder roads to cross the main channel at various points, creating likely sources of sediment and bed-load movement. In the summer of 1950, we made careful surveys of the stream bed at random intervals along its course which will enable us to measure any accumulations of bed load which do not reach the debris basin.

Basin plans draw on research results

In 1950 the Rocky Mountain Station has been called upon for an increasing amount of assistance in the formulation of plans for large river basins. Early in the year we were asked to submit a summary of research results and recommendations for the four major drainages in the region: Missouri, Arkansas, Rio Grande, and Colorado Rivers. This material was supplied to the President's Water Resources Policy Commission and was a partial basis for Volume 1 of the Commission's report which appeared in early 1951.

At the same time, planning has gone forward in all of these basins. The goal in each case is a comprehensive agricultural and water-development program. Properly conceived, they hold the key to increased wealth and production of the whole nation.

The Rocky Mountain Station has maintained an active part in these developments. Our research results have supplied important quantitative data on watershed-, range-, and forest-management potentials, and have helped form a basis for recommended land measures. The comprehensive plan for the Missouri River basin is now complete and awaiting Congressional action. In the 1950 Flood Control Act, strong impetus was given the development of similar plans on the combined drainage of the Arkansas, White, and Red Rivers. Activities in the Colorado and Rio Grande basins have not reached the stage of these other two, but are likely to do so in the future.

RANGE-MANAGEMENT RESEARCH

Millions of acres of rangeland in the Rocky Mountain region constitute a great natural resource. They support an important part of the nation's livestock industry, and extend throughout the headwaters of four major river basins. National security and economic stability depend on a sustained growth of forage on these rangelands. Anything less will lead to a decline in livestock production, land deterioration by erosion, and sediment-filled water supplies.

With a few minor exceptions, it is altogether possible to utilize the vegetative production of the range and still maintain desirable watershed conditions. The crux of the whole problem is to determine how far this utilization can safely go. It is not a simple problem. Every range-watershed situation presents variations which must be considered. The best hope is to devise guidelines for the range manager to follow, recognizing that each specific problem may require intelligent application of the basic fund of knowledge.

During its 15-year existence, the Rocky Mountain Forest and Range Experiment Station has directed a large share of its efforts to studies of range management. Our research program follows two major courses. One of these is the essential task of managing the existing forage resource. The second deals with rehabilitation of deteriorated rangeland by reseeding to bring back forage production and watershed control. These are discussed under the two general headings:

1. Grazing management.
2. Range reseeding.

GRAZING MANAGEMENT

First phase of pine-bunchgrass-management study is completed

In 1941 the Rocky Mountain Station began a study at Manitou Experimental Forest to learn more about the management of ponderosa pine-bunchgrass ranges in the Front Range. The specific objective has been to measure the effects of three intensities of grazing use on forage production and utilization, erosion and runoff rates, and cattle weight gains.

Six experimental pastures averaging 300 acres apiece, were stocked each year with yearling Hereford heifers. Each of the three grazing intensities--heavy, moderate, and light--was assigned at random to two pastures at the beginning of the treatment and continued on the same pastures each year following. Under heavy stocking, 60 to 70 percent of the total herbage

weight produced each season was utilized; under moderate, 30 to 40 percent; and under light stocking, 10 to 20 percent. Grazing began June 1 and ended October 31 each year.

The pastures represent conditions found along the upland valleys and parklike areas in the Front Range. Open grassland in the valley grades into a mixture of grass and ponderosa pine as the slopes ascend a broad alluvial bench. Grasses and sedges produce 94 percent of the total palatable herbage. Mountain muhly and Arizona fescue are the two basic forage species.

Moderate grazing is best for the land; best for the pocketbook

The effects of grazing intensity on vegetation and cattle gains have been sufficiently well established to enable us to report them in a forthcoming Department of Agriculture publication. All results point toward moderate grazing as the most desirable intensity of use.

Production and use of the vegetation under three intensities of use provided one of the best indicators of grazing effects. On heavily stocked pastures, grass and sedge herbage production dropped from 350 pounds per acre in 1942 to 195 pounds in 1947. Production on the moderately and lightly stocked pastures has not dropped during the study period. Both the open timber and grassland types respond to grazing use in a similar manner but the grassland areas produce much more herbage than those of open timber. Optimum use of pine-bunchgrass range appears to be about 35 to 40 percent of the annual production of herbage. This requires that 5 to 6 inches of stubble be left on Arizona fescue and 1½ to 2 inches on mountain muhly at the close of the grazing season.

Cattle gains are directly associated with the degree of grazing use. On heavily stocked pastures, gains have averaged 181 pounds per head for the 5-month season; on moderately stocked pastures, 222 pounds; and on lightly stocked pastures, 235 pounds. Weight gains are directly associated with the quality of the forage which varies during the season and between years.

Income per acre from moderate stocking was 55 percent greater than from heavy stocking because of increased livestock values and greater gains.

1950 grazing season shortened by drought

The 1950 season was very unfavorable for plant growth and development. Total rainfall for the year amounted to only 11.6 inches, or about 5 inches below the yearly average. Much of the summer rainfall occurred in small storms that were not effective in replacing soil moisture. The winter of 1949-50 was very dry, with a minimum of snow, and spring was not only dry but also too cold for normal growth. Some rains occurred during the summer in July, which gave a temporary boost to plant growth. The remainder of the season was deficient in moisture; plants matured early and were below normal in height growth and volume. Springs stopped running that never before have been known to fail. From a research

standpoint, it was an important season because of the crucial test applied to many of our studies.

Droughty conditions made it necessary to remove the heifers from the grazing-intensity pastures on September 26 instead of the customary October 31 date. Even so, the cattle on the heavily stocked pastures lost an average of 5 pounds per head during September. The total gain for the season was only 117, 179, and 208 pounds per head on heavily, moderately, and lightly stocked pastures, respectively. During this adverse season, the rate of cattle gains was nearly normal on the lightly stocked pastures, was slightly reduced on those moderately stocked, and greatly reduced on the heavily stocked pastures. In early August the heifers in the heavy-stocking treatments were showing the effect of poor pasture conditions. The hair was rough and they were gaunt and very unthrifty in appearance. Buyers would have penalized these animals severely if they would have taken them at all. In the other treatments, cattle were not affected so severely. They did not make normal gains but they were still thrifty and their appearance was more in keeping with good pasture conditions.

When the cupboard is bare they eat sagebrush

One of our major studies at Manitou Experimental Forest during 1950 was to determine when and to what extent cattle graze the major forage species. The study required 30 plots, each covering 25 square feet, in the three intensities of use. We estimated composition of the herbage by volume and utilization by species at the end of the grazing season. Utilization was also estimated at the intermediate periods of July 18 and August 15.

We estimated utilization on six forage species. These are listed in table 6 along with the percentage they represent in the total composition. All species were heavily utilized on areas where grazing was intense. Blue grama and fringed sagebrush received very low utilization on moderately and lightly used areas, whereas highly palatable little bluestem had relatively heavy use. Arizona fescue and mountain muhly provided the bulk of the diet on heavily and moderately used areas and were exceeded in use only by little bluestem on the lightly grazed plots.

In spite of the fact that cattle are forced to eat blue grama and fringed sagebrush on heavily grazed ranges, utilization checks show they are used about half as heavily as any of the other four species. This explains the ability of blue grama and fringed sagebrush to maintain themselves under heavy pressure. They become the dominant vegetation on overgrazed ponderosa pine-bunchgrass ranges as the preferred forage plants are killed by overuse.

Table 6.--Effect of grazing intensity on composition and utilization of six palatable forage species at end of 1950 grazing season. Manitou Experimental Forest

Species	Composition of vegetation: Heavy use	Moderate use	Light use	Utilization of herbage: Heavy use	Moderate use	Light use
	percent	percent	percent	percent	percent	percent
Little bluestem	5	1	2	60	31	21
Blue grama	21	3	1	28	1	0
Arizona fescue	11	41	21	71	36	13
Mountain muhly	38	45	57	71	39	15
Sedge	7	4	3	49	27	8
Fringed sagebrush	11	2	2	28	4	0
All species	93	96	86	54	35	14

Cattle change their diet with the season

Utilization checks made at three intervals during the summer of 1950 showed that heifers' choice of forage changed as the grazing season progressed. Arizona fescue and little bluestem were preferred grasses during the early part of the season. Later on, they lose their succulence and cattle turn to other species. Mountain muhly and blue grama received heavier use during the latter part of the season. Sedges appeared to be quite palatable at all times.

Grazing studies continued at Central Plains Experimental Range

Studies at the Central Plains Experimental Range were continued on 30 experimental pastures in the short-grass type. The main objective here is more efficient livestock production from the available forage supplies. In seeking this goal, however, we have not lost sight of the need for maintaining adequate watershed conditions. Efficient development of short-grass ranges must be guided by the need for well-managed soil and water resources as well as sustained forage production for a stable livestock industry.

During 1950, data for another year were added to the growing fund of information regarding the effect of heavy, moderate, and light grazing use on herbage production and cattle weights. We observed comparative use of forage plants and the relative merits of season-long moderate use versus double stocking during the early and late season.

Weather conditions in 1950 were not unusual

Precipitation totaled 11.9 inches, slightly more than the annual mean of 11.7 inches. Distribution of spring and summer rainfall, however, was

unfavorable for vegetative growth. Prior to July 1, only 4.5 inches were received with all months below average. This deficiency, coupled with low spring temperatures, hampered early growth. A storm in early July delivered $2\frac{1}{2}$ inches of rain and hail which flooded all waterways. Two well-timed showers brought another inch of moisture later in the month, and during September, $2\frac{1}{2}$ inches more were received. The short-grasses made lush growth in July and responded promptly to the later moisture in September.

Herbage production was somewhat less than normal. Highly palatable short-grasses like blue grama, buffalograss, and threadleaf sedge averaged only 390 pounds of air-dry herbage per acre compared with 510 pounds in 1949. The mid-grasses--bluestem wheatgrass, needle-and-thread, alkali sacaton, sand dropseed, and inland saltgrass--produced 83 pounds of air-dry herbage per acre, whereas the corresponding figure for last year was 170 pounds per acre.

Grazing use results in a wide range in herbage production

Forage plants that have been grazed at different intensities during previous years showed a wide range in herbage production. The following tabulation shows herbage production for 1950 in pounds per acre air-dry weight.

Grazing treatment	Herbage utilization (percent)	Herbage production Short-grass (Lbs./A)	Mid-grasses (Lbs./A)
Heavy	50	248	16
Moderate	40	386	59
Light	20	490	64

Early use reduces herbage production

Two additional grazing-management practices have been compared with season-long moderate use for a period of 8 years. These are early- and deferred-moderate use, both treatments aiming for 40-percent utilization. Early use runs from May 10 to August 10 and deferred use from August 10 to November 10. Herbage production per acre under all three grazing practices dropped off in 1950. The greatest loss in production occurred on the early-use pastures and the smallest loss was found on the deferred-use treatment. Loss in herbage weight produced by mid-grasses was much greater on the early-use treatment than that suffered by the short-grasses.

Blue grama is the outstanding short-grass forage species

Blue grama ranks highest in abundance, production, and palatability of all the short-grass species. In 1950 we studied comparative herbage production and utilization of short-grass species and found that blue grama produced 45 percent of the combined herbage growth of all perennial species grazed by cattle. Buffalograss (15 percent) and bluestem wheatgrass (14 percent) rank next as forage producers.

As far as cattle preference is concerned, blue grama ranks far ahead of any other species. Cattle show only moderate interest in sedges, sand dropseed, alkali sacaton, inland saltgrass, scurfpeas, and winterfat. Use of these species is usually less than 10 percent of current growth until blue grama use exceeds 40 percent. Heavy use of narrowleaf poison-vetch and slimstem milkvetch was observed where use of blue grama exceeded 50 percent. Heavy use of short-grass vegetation forces cattle to graze some plants they will not touch under any other circumstances.

Ten short-grass forage species given high to moderate grazing preference by cattle are, in order of choice:

1. Blue grama
2. Scarlet globemallow
3. Bluestem wheatgrass
4. Needle-and-thread
5. Buffalograss
6. Fourwing saltbush
7. Threadleaf sedge
8. Winterfat
9. Sand dropseed
10. Alkali sacaton

Moderate grazing paid the most

In 1950, returns from moderate grazing use grossed $510 more per square mile of range feed than heavy grazing use. Light use fell $990 short of heavy use and $1,500 short of moderate use because of current high prices and small number of animals grazed per square mile of range. Gross returns to the ranch income per square mile of range feed harvested in 1950 were $3,180 for moderate use, $2,670 for heavy use, and $1,680 for light grazing use.

Range-watershed studies evaluate mountain grasslands

In 1946, the Rocky Mountain Forest and Range Experiment Station undertook a research program on the Western Slope of Colorado with the full realization that a wide range of problems was awaiting study. A detailed analysis of these problems has shown that one of the most critical conditions exists in the spring-fall ranges in the pinyon-juniper type. Accordingly, in 1949 an extensive survey was made of plant-cover conditions accompanied by a series of plot measurements to determine rates of infiltration and soil loss.

In 1950 we shifted the same type of combined study to the mountain grasslands. Infiltration and erosion phases of the study have been discussed above (see page 19).

The primary purpose of these studies is to provide a sounder basis from which to judge range and watershed conditions, but they also provide a measure of health and relative productivity of mountain rangelands. At each of the infiltration sample sites we obtained herbage yields, density, and composition of the vegetative cover. Estimates were made (occasionally checked by clipping and weighing) on twenty-five $2\frac{1}{2}$-square-foot plots at each sampling site.

Observations included sites representing good stands of bunchgrass (Thurber fescue), thin stands of bunchgrass, bluegrass, brome-weed, needlegrass, lush weed, and poor weed conditions. Composition of each subtype is shown in table 4 (see page 19). Estimated yields are given in table 7.

Table 7.--Estimated herbage yields of mountain grassland subtypes, adjusted for utilization. Western Slope, Colorado. 1950.

Subtypes	No. sites sampled	Estimated yields, air-dry weight		
		Grass	Weeds	Total
		Lbs./A.	Lbs./A.	Lbs./A
Good bunchgrass	4	2,000	400	2,400
Poor bunchgrass	3	1,300	600	1,900
Bluegrass	3	1,000	500	1,500
Bromegrass-weed	1	800	800	1,600
Needlegrass	4	500	600	1,100
Lush weed	4	300	1,600	1,900
Poor weed	2	200	1,100	1,300

Grass density is greatest on good bunchgrass sites

The amount of ground surface covered with grass varied from 18 percent on good bunchgrass sites to only 2 percent on poor weed sites. Results indicate that Thurber fescue is generally replaced with weeds rather than other grasses when good stands of bunchgrass are thinned through grazing use. Weed density varied from a high of 36 percent on lush weed sites to a low of 14 percent on good bunchgrass slopes. Only on good bunchgrass sites was the grass cover greater than weed cover. Shrubs accounted for only a minor portion of the total plant cover on the sites examined. Densities for the various subtypes are listed in table 8.

Litter cover is greatest on good bunchgrass sites

Dead plant material covered over half the ground surface on good bunchgrass sites, compared with only 12 percent on poor-weed sites (table 5, page 20). Needlegrass and lush weed subtypes are also definitely inferior to good bunchgrass from the standpoint of litter cover. The amount of bare soil exposed on good bunchgrass areas was only 12 percent, while on poor weed sites it amounted to 62 percent.

Table 8.--Density and composition of grasses and weeds on sample plots in mountain grassland subtypes. Western Slope, Colorado. 1950.

Subtype	Density in percent of sample area			Composition in percent of total cover on sample area 1/	
	Grass	Weed	Total cover 1/	Grass	Weed
	percent	percent	percent	percent	percent
Good bunchgrass	18	14	32	56	44
Poor bunchgrass	12	20	32	38	62
Bluegrass	13	17	32	41	53
Bromegrass-weed	9	21	31	29	68
Needlegrass	8	19	29	28	66
Lush weed	5	36	41	12	88
Poor weed	2	23	26	8	88

1/ Includes minor amounts of shrubs making total cover slightly greater than the combined grass and weed cover for the bluegrass, bromegrass-weed, needlegrass, and poor weed types.

RANGE RESEEDING

Range reseeding is direct benefit to national welfare

One of the most direct contributions to national security made by the Rocky Mountain Forest and Range Experiment Station is through its reseeding investigations. Rangelands which are producing below their capacity are a threat to our welfare, particularly in times of emergency when all-out effort is needed. They are not carrying their share of the production load. Worse still, they are subject to the deteriorating influence of erosion and are a prime source of damaging sediment. If these semi-idle lands cannot be rehabilitated and returned to full production by range-management practices, range reseeding may be the answer.

The object of our research program is to determine suitable forage species, find out how to plant and grow them, and gage their productive capacities. In general, we have followed a three-step program:

1. Determine initial adaptability of forage plants to climate and elevation by row-plot trials;
2. Select the most likely of these for field trials and determine methods suitable for planting and reducing competition to get good stands.
3. Subject the most desirable of the species to pasture trials for grazing management and production tests.

At the present time our reseeding research program is being conducted in three general areas: the Front Range, the Western Slope in Colorado, and in the North Platte, Wind, and Big Horn River basins in Wyoming.

Additions were made to row plots at Manitou Experimental Forest

At the beginning of this year, row-plot trials at Manitou Experimental Forest included a total of 122 different plant species. Of these, 87 were grasses, 18 were legumes, 4 were other forbs, and 13 were shrubs. Ratings during 1950 indicated that 64 species were rated as good or excellent prospects for range reseeding. During November, 10 new species--3 grasses, 5 legumes, and 2 shrubs--were added. Replantings were made of tall wheatgrass which had winterkilled and *Elymus sabulosa* which had previously produced poor stands. Chokecherry and New Mexican locust were also replanted in an attempt to find shrubs suitable for erosion-control purposes.

These row plots continue to be one of the high lights for people visiting Manitou Experimental Forest. Here, ranch operators may see and compare the many different kinds of plants growing in close proximity. They can weigh advantages and disadvantages of each species and decide which plants best fill their own needs.

It's the survival of the fittest in field-plot trials

To date, 30 of the more promising forage plants have been tested under five different site conditions in the vicinity of the Manitou Experimental Forest. Many appear well adapted to a wide range of conditions. Others succumbed to the rigors of climate and competition. Some of the most successful are intermediate, crested, pubescent, Amur, and beardless wheatgrasses; smooth and meadow bromes; Russian wild-rye; and red fescue. All of these are well adapted to growing conditions in the Front Range. They vary in growth habit, season of growth, time of maturity, and other characteristics, thus furnishing a wide selection to meet various reseeding needs. At medium and high elevations, tall wheatgrass, orchardgrass, and stiffleaf wheatgrass were originally rated as excellent stands, but during the winter of 1949-50 these stands were almost completely killed.

Intermediate wheatgrass is top producer

Intermediate wheatgrass yielded the most herbage in almost all of the field plots from which yields were obtained. In spite of the extreme drought, the majority of these yields were far in excess of those from native grasses on adjacent areas of depleted range. Slender wheatgrass also produced high yields, but because of its relatively short life, it is not one of the better choices for range reseeding. Other grasses showing remarkable ability to produce under severe climatic conditions were crested and pubescent wheatgrasses, smooth and meadow bromes, and red fescue.

Steep south slopes resist reseeding attempts

One of the most difficult problems in the Front Range is to establish plants on steep, barren, south-facing slopes with a dense erosion pavement.

In the late fall of 1949 we planted seed of 12 grass species in small row plots for germination in spring, 1950. As was the case with similar trials in the spring of 1949, all species germinated well but the seedlings failed to establish. It is believed that the excessively high temperatures developed in the coarse gravel of the erosion pavement is responsible for the failure of the seedlings to survive. Apparently some type of shading is necessary. The quick-growing annual, Kochia scoparius (summer cypress) has done well in this area and, if planted along with the grass, may help in getting it established.

Cattle grazing provides final test

The value of a plant for reseeding purposes cannot be completely evaluated until it is tested under grazing. At Manitou Experimental Forest we are doing this in two separate locations. So far we have tried smooth brome, crested wheatgrass, a mixture of these two with yellow sweetclover added, and intermediate wheatgrass. Each of the four plantings are subjected to light, moderate, and heavy grazing.

The smooth brome pastures produced only 669 pounds of air-dry herbage per acre in 1950 as compared to 1,308 pounds in 1949 (table 9). Crested wheatgrass yields were also reduced from 2,091 pounds to 1,070 pounds per acre.

Table 9.--Herbage yields and cattle gains on reseeded pastures. (Averages for two locations) Manitou Experimental Forest. 1949-1950.

Species and year	Herbage yield	Total cattle gains	Gain per acre	Gain per day	Days of grazing
	Lbs./A	Lbs.	Lbs.	Lbs.	No.
Smooth brome					
1949	1,308	837	84	1.95	429
1950	669	350	35	1.32	266
Crested wheatgrass					
1949	2,091	983	98	1.78	553
1950	1,070	500	50	1.52	332
Mixture					
1949	2,585	1,263	126	2.00	630
1950	1,018	601	60	1.76	343
Intermediate wheatgrass					
1949	1,566	---	--	----	---
1950	1,769	837	84	1.73	485

Production from fields with a mixture of smooth brome, crested wheatgrass, and sweetclover showed the most severe reduction--a decrease from 2,585 pound per acre in 1949 to 1,018 pounds in 1950. Intermediate wheatgrass, however, increased from 1,566 pounds per acre in 1949 to 1,769 pounds in 1950.

Three factors may be involved in this increased yield of intermediate wheatgrass:

1. Yields in 1949 were obtained before the plants reached maturity.
2. The 1950 growing season was the third for intermediate wheatgrass. (Many reseeded grasses seem to reach a peak in vigor during the third year.)
3. Intermediate wheatgrass may have natural ability to produce more efficiently during dry years.

Cattle make good gains on intermediate wheatgrass

Intermediate wheatgrass pastures furnished an average of $48\frac{1}{2}$ days of grazing per acre; more than any of the other 10-acre reseeded pastures in 1950. Smooth brome furnished the least; crested wheatgrass, and the mixture were medium in grazing capacity. Cattle gains for the 1950 season ranged from a high of 84 pounds per acre on intermediate wheatgrass to a low of 35 pounds on smooth brome (see table 9). Gains on crested wheatgrass and the mixture were 50 and 60 pounds per acre, respectively. Daily gain was not as seriously affected, but the shortened grazing period resulted in lowered seasonal gain per acre.

Reseeding tried in four major types on Western Slope

Reseeding investigations on the Western Slope made good progress during 1950, but are not keeping pace with the needs of action programs now under way. The object of our present program is to determine suitable species and methods of reseeding four major types: (1) sagebrush; (2) pinyon-juniper; (3) mountain parks; and (4) salt desert shrub. Successful seeding in the first three of these types has made possible a comparison of species, sites, and methods of planting. Reseeding trials in the salt desert shrub type, however, have been very disappointing. Numerous drought-tolerant grasses have been planted at different dates without success. Small-scale tests of summer and winter fallowing, and different methods and times of seeding are being continued.

Studies continue in sagebrush type

Row-plot, field-plot, method-of-seeding, time-of-seeding, and sagebrush-chemical-control studies were maintained or enlarged in 1950. New field plots were established near Hotchkiss, Crawford, Sapinero, Mancos, Dolores, Norwood, Cimarron, and Wolcott. At three of these locations, both spring and fall dates of seeding were tested.

Drought condition in 1950 caused low herbage yields

Herbage yields from range plots in the sagebrush type were low in 1950 as compared to 1949. Precipitation was below normal for every month

in the growing season. Plots near Gunnison (seeded in the spring of 1947 at 8,000 feet elevation on alluvial soils) show wide variation between 1949 and 1950 in yields, based on production per acre, air-dry weight.

Species	Pounds per acre	
	1950	1949
Intermediate wheatgrass	973	2,778
Stiffhair wheatgrass	803	2,910
Crested wheatgrass	753	2,601
Tall wheatgrass	990	2,337
Smooth brome	335	1,279
Western wheatgrass	305	1,235
Tall oatgrass	121	1,058
Big bluegrass	137	529
Native grass on depleted sagebrush range	30	140

Promising characteristics show up in Crawford Nursery

At the end of the second growing season (1950), 43 species and 21 special strains were rated as excellent in row-plot trials at Crawford. Over one-third of these were wheatgrasses. Many others had good vigor and spread, but could not be classified as excellent because of poor initial establishment. The following adaptabilities were observed for some of the more important grasses:

1. For erosion control because of sod-forming characteristics:
   - Stiffleaf wheatgrass
   - Streambank wheatgrass
   - Thickspike wheatgrass
   - Western wheatgrass
   - Creeping red fescue
   - Creeping wild-rye
   - Blowout grass
2. For early spring growth and fall regrowth:
   - Crested wheatgrass
   - Intermediate wheatgrass
   - Pubescent wheatgrass
   - Tall wheatgrass
   - Big bluegrass
   - Bulbous bluegrass
   - Sandberg bluegrass
   - Bulbous barley
   - Muttongrass
   - Russian wild-rye
   - Tall oatgrass
3. For late-maturing growth, staying green in midsummer:
   - Intermediate wheatgrass
   - Pubescent wheatgrass
   - Tall wheatgrass
   - Western wheatgrass
   - Blowout grass
   - Fescues
   - Muhlys
   - Needlegrass
   - Weeping lovegrass
   - Wild-ryes

About 30 species of shrubs and herbs have also been planted at Crawford. The following were classed as excellent in 1950:

- Alfalfa (several varieties)
- Birdsfoot trefoil
- Chickpea milkvetch
- Fourwing saltbush
- Hairy vetch
- Red clover
- Sanfoin
- Trigonella
- Wormwood
- White sweetclover
- Yellow sweetclover

Seed the sagebrush country in late fall or early spring

For 2 years we have made monthly plantings of crested wheatgrass and smooth brome in row plots near Crawford from April through November. The study indicates that moisture conditions are most favorable for germination and growth of seedlings in the early spring. Plantings made in very early spring or late the previous fall are most likely to succeed.

In 1949, seed planted prior to July germinated immediately and made good stands. July plantings were near failures. Seed planted after July germinated in the late fall and made good stands the next year. In 1950, only the seed planted in April germinated immediately. Subsequent monthly plantings did not come up until fall rains in September. Seemingly, the erratic summer precipitation cannot be relied upon to promote germination and rapid growth of seedlings.

Some progress in control of sagebrush

Sagebrush plots at Crawford and Hotchkiss were sprayed in the spring of 1949 with three chemical treatments. These were 2,4-D, 2,4,5-T, and the two in mixture. We applied these chemicals on May 2, 25, and June 20, 1949, in three concentrations, using water and oil carriers.

Results were observed in June 1950. On the area near Hotchkiss where big sagebrush (*Artemisia tridentata*) occurred as almost a pure stand, the 2,4,5-T appeared slightly superior. At Crawford, black sagebrush (*Artemisia nova*) was mixed with big sagebrush and the plants, in general, were smaller. Here the differences between chemicals were not pronounced.

In all tests the amount of defoliation was in proportion to the rate of chemical applied. Effectiveness also appeared to be influenced by date of application. Growing conditions and stage of plant development are important in obtaining sagebrush kills and, in our tests, May seemed to be the best month to apply treatment. Oil carrier at 5 gallons per acre gave better results than water at 25, 50, or 100 gallons. The amount of water carrier made no consistent difference in results.

Tree and brush competition in pinyon-juniper type hampers reseeding effort

Extremely dry sites, shallow rocky soils, and tree competition make the establishment of plants very difficult in the pinyon-juniper type. Reseeded stands do well on the deeper soils at higher elevations characterized by thrifty sagebrush growing among the trees. At low elevations, however, drilling directly among the trees, or plowing and drilling, even when the trees were girdled to remove competition, has resulted in failures thus far. Twenty different drought-tolerant species have been tested at both early spring and late fall dates of planting, and monthly seedings of crested wheatgrass have been made, all without success.

In the spring of 1949 we began a study to test the effect of tree and brush competition on reseeding in the pinyon-juniper type near Crawford (elevation 7,200 feet). The site supported a good stand of big sagebrush in addition to the pinyon and juniper trees. Separate plots were seeded with crested wheatgrass and smooth brome by three methods:

1. Deep plowing to remove practically all sagebrush, followed by drilling.
2. Broadcast seeding and then covering the seed by disking, which removed less than 50 percent of the sagebrush.
3. Broadcasting pelletized seed with no seedbed preparation.

Pinyon and juniper trees were then removed or girdled on one-half of each plot. The following tabulation shows results from the first method, deep plowing and drilling. Data are given for July 1, 1950, in pounds per acre, air-dry weight.

	Pounds per acre
Trees removed	
Crested wheatgrass	330
Smooth brome	190
Trees undisturbed	
Crested wheatgrass	130
Smooth brome	50

Reseeded plants were nearly twice as numerous and much more vigorous where tree competition was removed. The second method, broadcast seeding and disking, produced only a few scattered plants of negligible yield, regardless of tree removal. Method 3, broadcasting pelletized seed with no seedbed preparation, resulted in complete failure.

Research expands in mountain parks

We have continued our search for adaptable plants and better methods for establishing them in the mountain park type. In 1950 new field-plot trials were established in five separate locations:

1. Gunnison National Forest.
2. Routt National Forest, California Park (reseeding followed deep and shallow plowing of Wyethia).
3. Medicine Bow National Forest (reseeding followed plowing of tarweed before its seed matured).
4. Grand Mesa National Forest (reseeding in spring and fall on sites prepared both by deep and shallow plowing).

Previously established row plots and field trials were continued. The row plots on Grand Mesa (10,000 feet elevation) were expanded to include 70 species and strains in 1949. These new row plantings, made in early July, were much more successful than previous ones made in the late fall of 1946.

Timothy makes best stands

Timothy has established and maintained more productive stands than any other of 10 species planted 4 years ago at several locations in the mountain park type. Other species tried are smooth brome, orchardgrass, meadow fescue, Kentucky and Canada bluegrass, redtop, slender, western, and crested wheatgrasses. Timothy is one of several grasses that have vigorous, rapidly developing seedlings, a characteristic which enables it to become established before weed competition becomes severe. Herbage yields were lower in 1950 than in 1949 because of unfavorable growing conditions, but timothy remained a top producer. Compared with 1949 results, meadow fescue and slender wheatgrass declined, and the slower establishing bluegrasses increased. Two legumes used in the tests, white and yellow sweetclovers, made very poor initial stands and had completely disappeared by 1950.

These 4-year-old plantings were among the first made by the Western Slope Research Center, and were designed to compare different species and methods of planting. They clearly demonstrated that plowing and drilling, or some method that reduces weed competition and covers the seed, is essential to successful reseeding. In our tests, neither drilling nor broadcasting seed on an unprepared seedbed have produced results in weedy mountain parks.

In spite of good seedbed preparation, some of these early seedings made relatively poor stands. Failures caused us to focus our attention on competing plants such as sneezeweed, tarweed, hairy goldaster, showy goldeneye, and mules-ears wyethia or resinweed. We have studied methods of seedbed preparation, depth of plowing, and chemical control as a means of controlling some of the more aggressive of these weeds.

Orange sneezeweed and hairy goldaster can be controlled

Our reseeding tests on the Uncompahgre Plateau show that orange sneezeweed can be greatly reduced by shallow plowing or disking. Seedbeds should be prepared before sneezeweed matures its seed, preferably in early July. Reseeding of adapted grasses should follow immediately. Seeding should be heavy to provide a good ground cover quickly, thereby preventing the reinvasion of sneezeweed seedlings.

Sneezeweed also can be virtually eliminated by application of 2,4-D sprays. Native grasses are not killed and may increase in density and yield after weed competition is reduced. Drilling grass seed directly, a few weeks after 2,4-D sprays have eliminated the weeds, offers a promising method of range improvement on areas not suited to tillage.

Hairy goldaster parks common to the plateau country can also be converted to productive grasslands according to tests on the Uncompahgre National Forest. Although hairy goldaster is very deep-rooted, removal of the plant by relatively shallow plowing is sufficient for the establishment of reseeded grasses. Disking after plowing results in even more thorough removal of the plants and higher yields of reseeded plants.

In 1950, a 3-year-old stand of timothy produced 704 pounds per acre on a plowed and drilled area as compared to 65 pounds of native grass on a hairy goldaster park protected from grazing for 11 years.

Reseeding mountain parks requires careful management

Mountain parks normally present a grazing-management problem. Before reseeding, they are usually concentration areas for livestock and after planting the new grass tends to attract even more stock. Comparatively small seeded areas of 50 to 300 acres surrounded by large areas of native range are liable to be severely overgrazed unless use is closely regulated. For this reason range managers sometimes question the feasibility of planting grass in small mountain parks.

We had an opportunity to make some observations in 1950, however, which indicate that small reseeded parks may be used properly in conjunction with native range if water is available and stock are removed at the proper time. One hundred acres had been fenced to include approximately 50 acres of depleted mountain park type producing less than 100 pounds of native grass per acre and a remaining area in aspen and spruce-fir types producing nearly 200 pounds of forage per acre. The 50 acres of parkland were reseeded in 1947. Forty acres were planted with timothy and 10 acres with Canada bluegrass which produced 925 and 570 pounds per acre, respectively, of air-dry herbage in 1950.

Cattle grazed the area in 1950 for 19 days (August 24 to September 11) and were removed when the average utilization of timothy was 40 percent. Canada bluegrass and native grasses were utilized somewhat less. Heaviest use was in the immediate vicinity of the water supply, but even here grasses were apparently not damaged. Before reseeding, the area should have supported about 300 cow-days of grazing if utilization of all grasses had been 40 percent. After reseeding one-half of the area, it supported 950 cow-days of use.

Studies continued in Wyoming

Our range-management-research program in Wyoming has been under way for 3 years. At the present time we are working only with the reseeding and brush-control phases. Reseeding studies are in cooperation with the Bureau of Land Management at whose request we have extended our program to include chemical spraying of big sagebrush. We have also engaged in a four-way cooperative project with the Bureau of Land Management, Soil Conservation Service, and University of Wyoming to study methods of getting stands of grass on the raw, eroding soils of the Guernsey-Glendo demonstration area.

Sagebrush is also a problem in Wyoming

In 1949 and 1950 we experimented with chemical control of big sagebrush, using methods similar to those employed on the Western Slope of Colorado. In 1949 the best kill (97 percent of the plants) was obtained

with $1\frac{1}{2}$ pounds of 2,4-D in 50 gallons of water. In 1950 both contact sprays and growth regulators (2,4-D and 2,4,5-T plus mixtures of the two) were used with oil carrier and water carrier at several concentrations. Spraying was done on May 20, June 5, and June 25 with both ground rig and airplane. Judging from October defoliation, chemical control offers promise, but there is still considerable experimental work ahead of us.

Reseeding efforts are wasted unless competition is reduced

In 1950 we began to see the effect of killing native vegetation on the growth of grass seedings made in 1948. Where this was done in both sagebrush and salt desert shrub types, the number of 2-year-old grass plants has been increased at least 45 times. Seedbed preparation resulted in an average of two plants per square foot for all species rated good. On unprepared seedbeds, these same species produced an average of only one plant in 45 square feet, a ratio of 90 to 1 in favor of seedbed preparation. For crested wheatgrass and Russian wild-rye corresponding ratios were 50 to 1 and 250 to 1, respectively.

Species ratings (excellent, good, fair, poor, very poor) for the 2-year-old stands on prepared seedbeds were:

Rating	Sagebrush type	Salt desert shrub type
Good	Amur wheatgrass Crested wheatgrass Rhizomatous crested wheatgrass Russian wild-rye	Rhizomatous crested wheatgrass
Fair	Intermediate wheatgrass Pubescent wheatgrass	Crested wheatgrass Russian wild-rye
Poor	Indian ricegrass Beardless wheatgrass Western wheatgrass	Intermediate wheatgrass Pubescent wheatgrass Amur wheatgrass
Very poor	Tall wheatgrass	Tall wheatgrass Beardless wheatgrass Western wheatgrass Indian ricegrass

Plowing and mulching favors seedlings

In 1949 we made some tests on severely eroded areas in the Guernsey-Glendo demonstration area to see what effect mulching would have on seedling development. As a part of the same study we tried two types of seedbed preparation--plowing and grading--to reduce competition from native vegetation.

Our 1950 examination of the seven species tested showed a fourfold increase on sites plowed and mulched with straw. These are the results:

Seedbed treatment	Average number of seedlings per sq. ft.		
	Straw mulch	Manure mulch	No mulch
Plowed	1.9	1.3	1.0
Graded	1.3	1.1	0.5
No treatment	1.5	1.3	0.5

The development of these and similar methods for revegetating raw, eroding sites is an extremely practical line of endeavor. Even if the vegetation never yields an ounce of forage for livestock, it is performing a valuable function in protecting vital water supplies and water-control installations. Furthermore, it performs the less dramatic but altogether basic function of improving the site from which the damaging runoff originated.

Artificial fertilizers improve ranges on granitic soils

Plot studies in the treatment of range soils with mineral fertilizers have failed to show any response to the surface application of minor elements applied in 1947. In 1949, we worked the fertilizers into the surface inch of soil with a hoe, but this mixing was far short of that found to be necessary in agricultural practice. Heavy applications of lime, nitrogen, phosphorus, and potassium were made in different combinations. The only response obtained from these treatments was on soils developed from granite, granitic alluvium, and granite-gneiss. Plots on these three sites all showed a marked response to treatment of lime plus nitrogen-phosphorus-potassium. Lime plus potassium gave a moderate growth in two plots, and lime plus phosphorus-potassium showed a weak but suggestive response in some places. Had these fertilizers been well mixed and plowed into the soil, better results could have been expected. The four plots that showed no response to any fertilizer treatments were on soils developed from basalt, andesite, Morrison shale, and an alluvial deposit consisting of a wide variety of rocks.

FOREST-MANAGEMENT RESEARCH

Forested lands in the Rocky Mountain region have the capacity to produce more usable wood. Present timber growth is estimated to be 50 to 60 board feet per acre per year. This could be doubled in two ways.

One of these is by a more rapid harvest and better utilization of the mature stands, which are growing slowly, or losing ground through disease and death. To increase production it will be necessary to build many miles of roads and improve the efficiency of high-altitude logging methods. Waste in the woods can be reduced and discarded material at the mill utilized more efficiently. Logging and utilization problems in the region have thus far hampered the removal of old growth.

The second way to improve production is to develop cutting methods which provide for more adequate stocking and growth of the commercially desirable lumber- and pulp-producing trees. Forests under intensive sustained-yield management are capable of outstripping the production of timber that just happens to grow. But forest-management techniques in the Rocky Mountain region have not been developed to the extent that they have in other regions. Management practices had to be adapted from elsewhere without any basis for modifications to fit local tree species and growing conditions.

Cultural practices to increase growth are tested

We have started on a research program at Fraser Experimental Forest designed to improve techniques in cutting practices. At present our activities deal largely with lodgepole pine and the Engelmann spruce-alpine fir types. These are the most important in the Rocky Mountain region. Each type occupies around 3 million acres in Colorado and Wyoming, and together they constitute 75 percent of the merchantable timber resources within the national-forest boundaries. The area they cover also coincides with the zone of greatest water production. These combined values of timber and water form the basis for our research program.

Harvest-cutting plots are the first step

At Fraser Experimental Forest we have so far devoted most of our attention to cutting treatments on relatively small plots in both the lodgepole pine and spruce-fir types. Timber was cut in the lodgepole pine plots (see page 8) in 1939-40 to test the effect of partial removal by selecting individual trees. Windfall mortality among the remaining trees was so high that we directed our attention to group rather than

single-tree systems of cutting. In subsequent tests with the spruce-fir type on 8-acre plots, we tried alternate clear-cut strips 1 chain wide and circular groups 1 chain in diameter. These were tested along with individual-tree selection to determine relative advantages, both as silvicultural and watershed-management practices.

Uncut strips are wind barriers

So far, the most efficient all-around system is the alternate clear-cut strip with uncut strips of timber remaining between. The method shows promise for both lodgepole pine and spruce-fir types. It offers wind protection, a perpetual seed source, and allows regeneration of desirable species which are not tolerant to the shade of an overstory.

The next step in our program will be the application of plot results to a more complete study on Fool Creek watershed. On this testing ground, we can observe results under conditions which duplicate standard logging situations and at the same time will yield complete information on water yield and erosion. The study will also provide an opportunity to learn more about methods of road construction and logging techniques.

Strip cutting being planned

We are now making plans to harvest the timber in Fool Creek by alternate clear-cut strips varying in width from 100 to 200 feet. In planning their location on steep slopes such as those of Fool Creek, two major considerations will govern direction of the long axis. One of these is the need for an orientation as nearly perpendicular as possible to the direction of destructive winds. This is to achieve maximum protection from blow-down. The second is a requirement that strips run up and down the slope to provide for most efficient logging.

Obviously, in mountainous terrain, both ideals cannot be met except in limited situations. However, it appears likely from our cutting in the spruce-fir plots that some latitude in application is possible. Strip orientation from the standpoint of wind protection, may deviate possibly as much as 45° either way from the ideal. For one thing, destructive winds will vary around the prevailing direction. Also, there is some indication from our studies that the angle at which winds travel across the strips may deviate somewhat from perpendicular without serious increase in blow-down hazard. The requirement that logging be done downslope to reach feeder roads built on a contour level is somewhat less flexible. However, this advantage is not destroyed by introducing a slight angle to the right or left of normal.

Direction of destructive wind must be known

Prior to 1950 we had very little knowledge of wind movements in Fool Creek. We did know from earlier studies in Colorado and Wyoming, however, that local variations can be very pronounced. This information

was obtained by making tallies of the direction in which blown-down trees lay on the ground. The survey showed that, in general, trees are thrown by prevailing west and southwest winds. Studies in the 36-square-mile area of Fraser Experimental Forest, however, showed that local land features can cause variations of as much as 125° in direction of prevailing winds.

Realizing that detailed studies were necessary in Fool Creek itself, we made a sample-plot survey in 1950 to determine the direction in which the greatest number of trees had been thrown. A record was made on each quarter-acre plot of all down timber in the pole and sawlog sizes.

Data were separated into three classes of windfalls, based on the conditions under which they were blown down. This classification was made because it was thought at the outset that chosen categories represented distinct differences in reliability as indicators of destructive wind direction. Classes are shown in descending order of estimated reliability:

Class 1.--Windfalls with extensive root systems showing evidence of being alive when blown down.
Class 2.--Windfalls whose roots indicated that the trees were dead snags before they fell.
Class 3.--Windfalls which were broken off above the ground line because of rot or other defect in the trunk.

West wind causes blow-down in Fool Creek

Results of the tally show that the destructive winds in the watershed blow from due west. Some variations were evident throughout the watershed, but they do not seem important for the practical aspects of strip orientation.

Deviation of windfall bearings was least on the watershed ridges. They are occupied primarily by lodgepole pine at the lower elevations and mixed Engelmann spruce and alpine fir higher up. Of the two forest types, lodgepole pine, in general, showed less deviation in windfall bearing. Windfalls of the spruce-fir type were somewhat less reliable indicators. Spruce and fir growing along the stream bed and in particularly moist areas had the greatest tendency to fall randomly without any apparent reflection of wind direction. With the exception of those found on the very moist sites, windfalls in both lodgepole pine and spruce-fir types were sufficiently reliable to help guide strip orientation.

All classes of down trees are good indicators

The average direction of fall for windfalls in class 1 (living trees prior to blow-down) was 93°, azimuth bearing--almost due east. Two-thirds of all down timber fell within 60° of this bearing. Class 2 windfalls (dead trees prior to blow-down) were oriented around an average bearing of 89°, two-thirds falling within 65° of the average. An average

direction of 90° was found for class 3 windfalls (trees broken off above the ground line). Thus it is apparent that all three classes of down trees not only fell in approximately the same direction, but were all about equally reliable indicators of wind direction. All showed a strong and definite tendency to fall with the destructive westerly winds.

Less sampling caution needed on a timber sale

This windfall study was made especially intensive because of the unknown nature of the problem and the detailed information required. Practical application of the method would not require nearly as much data. A sample of 1 or 2 percent of the area, or from 150 to 200 down trees with extensive root systems should be sufficient if well distributed over the cutting area. Special effort should be made to assure a broad time distribution by utilizing to the utmost all mounds indicating very old windfalls. It is important to avoid tallying trees that have fallen under the influence of other falling trees.

Road system planned for logging

A large part of our effort at Fraser Experimental Forest in 1950 was in preparation for the logging treatment of Fool Creek. One of the major jobs was a survey of spur logging roads. For maximum watershed protection, we attempted the ideal of completely level roads following the watershed contours. This presented difficulties in application. Grades up to 5 percent for short distances were often necessary to avoid difficult construction and undesirable stream crossings. Another difficulty was in maintaining an optimum of 400 to 600 feet distance between spur roads for efficient log skidding. Nevertheless, the maximum average grade on any of these roads was maintained at 3 percent or less.

Young ponderosa pine grow better on lightly grazed ranges

In 1950 we analyzed the effect of three intensities of grazing on young pine at Manitou Experimental Forest. A series of 12 plots, 4 in each grazing intensity, was established in the management pastures in 1941. In each plot we tagged 10 trees and measured their heights. We also recorded the number of cases of damage per tree from cattle nipping on shoots and rodents chewing on the bark. A reexamination made in 1949 showed a trend toward growth hindrance and increased damage on the heavily grazed plots. Both are attributed to cattle because there was no apparent difference in the attacks by rodents. The data imply that heavy grazing is detrimental to growth of trees in the seedling stage. However, there is no evidence yet that damage has been fatal. Also, there is reason to believe that while these trees increase slowly in height, they will eventually outgrow the stage where cattle can inflict serious damage to the crown.

OUR COOPERATORS

The work of the Rocky Mountain Forest and Range Experiment Station was made easier and more productive because of the wholehearted cooperation of many individuals and organizations. It has been gratifying to know that they have enough faith in the works of the researcher to give him a helping hand. We have confidence that they in return have gained in some measure from our efforts to improve ranges, forests, and watersheds.

The following cooperators are listed by geographic location of our research programs.

Front Range

Soil Conservation Service, Colo. Springs
Agricultural Extension Service, Colo. Springs
Turkey Creek Ranch, Colo. Springs
Clyde Denney, Woodland Park
F. L. Hammer, Woodland Park
Frank Harbour, Woodland Park
Bill Matheny, Woodland Park
The Worden Ranch, Woodland Park
Frank O'Brien, Jefferson
Lee Wallace, Jefferson
Joe Kauba, Castle Rock
Hugh Bennett Ranch, Falcon
H. H. McDannald, Hartsel
Lyman G. Linger, Loveland
Arthur Colard, Lyons
Schuler Bros., Estes Park

Western Slope

Bureau of Land Management
    Evert L. Brown, Montrose
Soil Conservation Service
    C. G. Marshall, Albuquerque
    J. E. Downs, Albuquerque
Colorado Agricultural Extension Service, Fort Collins
    R. E. Ford
    C. L. Terrell
Fleming Lumber & Mercantile Company
    John McAllister, Minturn
Fred L. Garrison, Rifle
Lester E. Hammond, Crawford
Richard C. Klaseen, Crawford
Wallace R. Klaseen, Crawford
Wetsel Allen, Dolores
G. D. Taylor, Dolores
George Soderquist, Cimarron
Genevieve Hartig, Delta
Ralph M. Myers, Gunnison
Harry S. Wood, Hotchkiss
Howard Davis, Norwood
J. C. Bown, Wolcott

Central Plains

Crow Valley Livestock Cooperative Association
    Secretary--Elmer P. Ball, Briggsdale
    Cooperating members--
        Archie Calder, Nunn
        Duncan Calder, Nunn
        A. T. DePorter, Carr
        Murray E. Giffin, Nunn
        G. H. Grove & Son, Eaton
        Floyd Mason & Son, Bellvue
        James McCartney, Briggsdale
        McKay Bros., Grover
        F. E. Murphy, Briggsdale
        Russell Peterson, Nunn
        Harvey Pollock, Greeley
        Russell Pollock, Nunn
        Henry Prange, Carr
        Raymond Prange, Carr
        Harry Raven, Purcell
        Alex Werner, Grover
        Fred Werner, Grover
        Frank R. Williams Estate, Nunn
    Cooperating employees--
        Paul Holberg, Purcell
        Burdette C. Rush, Nunn

Cooperating cattle feeders
    A. W. Avery, Greeley
    Ted Sutter, Greeley

Soil Conservation Service
    Neal P. McKinstry, Briggsdale
    Jules Renaud, Fort Collins

Volunteer Fire Department, Nunn

Continental Divide

Bureau of Reclamation, Denver
    J. R. Riter
    H. S. Riesbol
    W. U. Garstka
    F. A. Bertle

Denver Water Board, Winter Park

Bureau of Plant Industry, Soils, & Agric. Engineering
    Stewart Andrews, Albuquerque
    Lake S. Gill, Albuquerque

M. A. Bunger, Denver

Wyoming

Bureau of Land Management
    Floyd D. Larson, Billings, Mont.
    Lester Brooks, Lander, Wyo.
    W. T. Vaughn, Lander, Wyo.
    John Killough, Rock Springs, Wyo.
    Harold LeSueur, Worland, Wyo.

American Chemical Paint Co., Ambler, Pa.

Dow Chemical Co., Midland, Mich.

DuPont de Nemours Co., Wilmington, Del.

Big Horn Flying Service
    Melvin Christler, Greybull, Wyo.

Soil Conservation Service
    State Office, Laramie, Wyo.

University of Wyoming, Laramie
    A. A. Beetle, Agric.Exp.Sta.

Wyoming Agricultural Extension Service, Laramie

L. A. Armagost, Casper, Wyo.

Howard Flitner, Greybull, Wyo.

A. C. Hildreth, Horticultural Field Station, Cheyenne, Wyo.

In 1950, a number of organizations, both State and Federal, engaged in research projects under cooperative arrangements with the Rocky Mountain Station. The following statements summarize the activities of those cooperating organizations not included elsewhere in this report.

FOREST INSECT INVESTIGATIONS
(Bureau of Entomology and Plant Quarantine
in cooperation with the Forest Service)

The Engelmann spruce beetle control project was the main concern of the Forest Insect Laboratory in 1950. All other research activities were placed in the background in order to assist the Forest Service by making surveys of infested areas for operations and investigating new ways to improve control methods. This has been an emergency control operation. The beetles have already killed approximately 4.5 million board feet of spruce and lodgepole pine in Colorado. Unless control operations are continued, much of the remaining spruce of Colorado, southern Wyoming, and northern New Mexico may suffer heavy mortality by spread of the outbreak.

Engelmann spruce beetle control campaign is started

After considerable delay, Congress passed a bill on June 27 appropriating $2 million for control of the Engelmann spruce beetle in 1950. As a result of planning a minimum of delay was necessary in construction of roads, establishment of camps, assemblage of material and equipment, and recruitment of labor. By July 26, 10 camps were established and operating. After that date three more camps were established, and two were moved into new areas. Most of the treating was terminated on October 6, although some camps remained in operation until October 26. A total of 784,082 trees were treated on 33,301 acres. Of this number, 619,688 were 1949-attacked trees, and 164,394 were 1950-attacked trees. Although the production exceeded expectations, it was not possible to treat most of the 1950 attacks, 192,300 of the 1949 attacks on Red Table Mountain, and 156,000 of the 1949 attacks on Castle Peak. All 1949-attacked trees were treated in other control areas. A mixture of one part orthodichlorobenzene to six parts fuel oil was used in the treatment. A total of 1,003,253 gallons of this mixture was used on the project, or 1.28 gallons per tree. Average cost per tree was $2.26.

Surveys determine the number of spruce infested in 1950

Much was accomplished in 1950 toward bringing the Engelmann spruce beetle under control, but even greater accomplishments will be necessary in 1951 and 1952. Exclusive of the area on the Routt National Forest south of Rabbit Ear Pass, there are an estimated 1,546,570 trees infested in 1950 and in need of control in 1951 on the White River, Arapaho, and Routt National Forests. In the area south of Rabbit Ear Pass, there were 324,500 trees infested in 1950. A large number of trees will be infested in 1951 in Routt National Forest north and south of Rabbit Ear Pass, where no control could be carried out in 1950, and on Red Table Mountain and

Castle Peak, where only partial control was possible. Surveys to detect and appraise beetle infestations covered an area of 2,800,000 acres on the White River, Routt, and Arapaho National Forests and Rocky Mountain National Park.

Woodpeckers are most important natural enemies of the spruce beetle

Woodpecker population has built up to two or more per acre in the beetle-outbreak areas, but this number is not sufficient to control the overwhelming spruce beetle population. They have, however, decimated the beetle population in many of the outlying spot infestations. Likewise, they have destroyed the brood in many trees within the control areas. The control program is supplemental rather than competitive with the woodpeckers. No woodpecker mortality from the use of orthodichlorobenzene has been observed. The three most important species are the alpine three-toed, the Rocky Mountain hairy, and the downy woodpeckers.

Ethylene dibromide is effective against Black Hills and Engelmann spruce beetles

Experimentation with many new insecticides has brought out one new material, ethylene dibromide, which is ready for field use in controlling the Engelmann spruce and Black Hills beetles. It can be used in oil solutions against both species of beetle, or in water emulsion against the Black Hills beetle. Unfortunately, the emulsion form is not effective against the Engelmann spruce beetle. Emulsion is made from an emulsifiable concentrate containing 2 pounds of ethylene dibromide, 0.5 pound of emulsifier, and sufficient No. 1 fuel oil to make 1 gallon of solution. One gallon of this stock solution is added to 4 gallons of water to make the emulsion. Oil solution in which no water is used, is made by adding 1.5 pounds of ethylene dibromide to 5 gallons of fuel oil.

Aerial application of DDT successful against two forest defoliators

Aerial application of DDT at the rate of 1 pound to a gallon of water per acre was applied by contact to control the Great Basin tent caterpillar and the spruce budworm in northern New Mexico. The spruce budworm had defoliated the white fir on the Sandia Recreational Area, Cibola National Forest, to the point where control was necessary in 1950 to save the stand. An area of 4,800 acres was sprayed with highly successful results. While the immediate results of the spraying of 15,600 acres of aspen in heavily used recreational areas on the Carson and Santa Fe National Forests were equally good, many mature larvae invaded the sprayed areas to lay eggs for the 1951 generation. The low value of the aspen stands, however, precludes the possibility of spraying the many thousands of acres of aspen being defoliated by the Great Basin tent caterpillar.

OBSERVATIONS ON DETERIORATION OF BEETLE-KILLED SPRUCE[5/]

(Bureau of Plant Industry, Soils, and Agricultural Engineering, in cooperation with the Forest Service)

This report is the result of a preliminary survey of decay in beetle-killed Engelmann spruce of Colorado. The purpose is to point out where further research can aid in developing plans for the salvage operation. For best information, intensive studies should begin soon and be continued as decay progresses. However, it is hoped that present information will help guide salvage operations while more is being learned.

In areas where the epidemic first started saprot is coming in from the roots and shows up in the butt section of the trunk where it sometimes extends into the heartwood. The basal saprot is almost always brown rot. There is little evidence of decay coming into the sapwood of the trunks or tops except where tops are broken, or were dead before the beetle kill. It may be that moisture entering the larger cracks will eventually result in some localized rot, but it is doubtful whether decay in the upper trunk or tops will be a major problem soon as there are now many old dead standing trees in the stand with sound trunks and tops.

Observations of this summer indicate a surprising incidence of heart rot, but since no adequate study has been made of heart rot in spruce, especially of Mesa type spruce stands, it is not possible to give an estimate of loss. From observations in logging areas on Clark Ridge and Clinetop Mesa a large proportion of the trees contained some butt rot at the time they were killed. Quite a few long butts are left by the loggers.

Heart rots in the trunks and tops are also of frequent incidence, but it is doubtful whether such rots will progress to any great extent in dead timber. Decay in the top will probably not continue to spread unless a break or a fork permits water from rains and snows to enter. In general, however, the tops have dried out to the point where further decay is not possible.

It is known that wood must contain more than 20 percent moisture before decay can take place. Measurements have shown that moisture content of logs at the mills is very low and further tests made this summer indicate that the upper trunk of standing trees contains wood that is below 20 percent in moisture content. Final loss of killed timber, however, does not depend necessarily on decay in the upper trunk or tops, whereas trees which decay at the base and fall over may be a total loss in only a few years.

Wind damage to dead spruce on the White River National Forest is most severe on the west edge or in the area of oldest kill. The most extensive damage is to the larger and older trees weakened by butt rot or other defects at their base. Some of this wind damage was present in more recently killed stands. An occasional tree of Coffee Pot Mesa and a few in the Willow Creek area north of Trapper's Lake had blown over.

5/ Studies made by Ross W. Davidson, pathologist, Beltsville, Md.

From information obtained to date it seems that small amounts of decay, especially in larger pulpwood bolts, should not cause them to be discarded. For instance, a 26-inch bolt with a 2-inch or even 6-inch column of rot in the center would contain more sound wood than an equal volume of wood in 8-inch diameter bolts. This opinion is based on the supposition that advanced brown rot (most often present) can be removed at the mill or will float off or be sifted out in the pulping process and not affect the quality of the pulp materially.

FOREST-RANGE-WILDLIFE RESEARCH
(U. S. Fish and Wildlife Service in cooperation with the Forest Service)

Although the Fish and Wildlife Service was unable to place a man on Grand Mesa throughout the summer of 1950, observations made in the fall gave further indication of a possible relationship between gopher populations and the abundance of forbs. Extensive treatments carried out by the Forest Service in collaboration with insecticide and farm-equipment companies in the summer of 1950 give a basis of appraisal which will be made in the spring of 1951. The treated areas are near the 16 experimental gopher plots established in 1951 on Grand Mesa.

Various treatments applied have been recorded and the plots carefully staked. As soon as snow conditions permit in the early summer of 1951, a careful inspection of these plots will be made and the abundance of the gopher sign compared to that present on comparable untreated areas. These observations should indicate whether herbicide treatment, resulting in the killing of forbs upon which gophers live extensively will have an over-all effect on gopher populations.

Formerly established gopher plots were also inspected on September 15. The over-all picture was one of gopher scarcity brought about, no doubt, by pronounced dryness during the summer. Last winter's "cores" and early spring mounds were prevalent throughout the area, indicating gopher activity earlier in the season.

Gophers more plentiful on plots where they have been trapped

A most interesting observation was made on the sixteen 1-acre gopher-study plots. When the plots were established in 1941, four treatments were applied, each of which was repeated in four groups of plots. Each plot was inspected on September 15, 1950, with the idea of noting the number of separate gopher runways. Whereas there was some uncertainty regarding the limits of individual runways, on the whole, the appraisal was adequate for the comparison of one group of plots with another. The number of recently active runways, as revealed by fresh mounds on the four differently treated experimental plots, is shown in table 10.

Table 10.--Number of recently active runways on 16 plots wherein cattle and gophers have been controlled. Grand Mesa, Colorado. 1950.

Groups	Treatments: No gophers: No cattle	No gophers: Cattle	Gophers: No cattle	Gophers: Cattle	Totals
I	2	0	2	5	9
II	15	11	0	2	28
III	10	16	1	1	28
IV	26	19	1	0	46
Totals	53	46	4	8	111

It will be noted that (with the exception of plots in group I), more recent gopher activity was found on the units that had been trapped for 9 years than those on which no trapping was done. Group I, as a rule, had fewer gophers through the years than the other three and may be construed as being somewhat out of line in its relation to this problem. Why recent gopher activity should be so much more pronounced on the trapped areas cannot be explained at this time. As a matter of fact, more gopher activity was found on the trapped plots in groups II, III, and IV, than anywhere else on the open range of Grand Mesa. On the other hand, the scarcity of recent gopher work on the plots which had not been trapped compared very favorably with gopher evidence on Grand Mesa as a whole.

GEOLOGY AND EROSION STUDIES6/

(Colorado A & M College, Department of Geology, in cooperation with the Forest Service)

Observations made in the watershed of the Cache la Poudre River, Larimer County, Colorado, indicate that there has been a noticeable rejuvenation of erosion during recent times. Downcutting and headward erosion is active in a number of drainageways which were formerly stabilized by vegetation. Also, a number of upland areas which appear to have been reasonably stable are now being actively eroded. This condition is not unique; rather, it has been observed and reported by many workers in the West and Southwest. In order to present a picture that is not misleading, it should be stated that not all areas show recent rejuvenation. Areas underlain by rocks of superior resistance to weathering and erosion show little evidence of increased erosional activity.

Rejuvenation of erosion has taken place many times in the geologic past. Major erosion cycles are interpreted by geologists as being the results of uplift and the minor ones, the results of climatic changes destroying the equilibrium previously established. If these are causes of

6/ Initiated by D. V. Harris, Department of Geology, during June 1949.

rejuvenations of the past, they should be considered also as possible causes of the recent cycle of erosion. In certain cases, this recent increase in erosional activity has apparently begun since modern man occupied the areas involved, and it is accepted by many that his activities are responsible. Studies by many careful workers leave little doubt that erosion in certain areas has been accelerated by overgrazing, by deforestation, and by improper cultivation practices.

However, it appears advantageous also to investigate uplift and climatic change, directly or in connection with man's activities, as possible causes for the recent rejuvenation. If geologic uplift is considered a cause, it would be necessary to submit evidence that an uplift had taken place during the past few hundred years. It is generally believed that any significant uplift would be accompanied by earth tremors or earthquakes. No recent earthquakes of significance have been recorded in the Southern Rocky Mountain province. Also, there are many balanced rocks and pedestal rocks throughout the region. A long period of time was required to develop these features and they most certainly would have been shaken down if any significant earthquake had taken place. Therefore, there seems to be no basis for interpreting the recent cycle of erosion as a result of geologic uplift.

The interpretation that erosion may be reactivated by changes in climate has been accepted by many geologists and applied mainly to the geologic past. It was suggested by Ellsworth Huntington a few decades ago as a possible cause for the recent rejuvenation in the Southwest. He reasoned that under a given climatic regime, erosion takes place at a certain rate depending on slope, soils, and vegetation. Should the climate become drier, the vegetation would become less dense and less able to hold the soil in place. Therefore, erosion would become active. If this reasoning is sound, then it is necessary to establish the fact that climates have become drier.

A geologic approach to the problem takes us back to the last major advance of mountain glaciers. At that time climates were colder and more moist than at the present time. The melting of the glacial ice resulted from a change toward a drier and warmer climate. This change was not made at a constant rate. In fact, there were minor reversals in climate which caused some readvances of the glaciers. However, the fact that the few tiny glaciers remaining at the latitude of Fort Collins are confined to their cirques at high elevations is proof that the general trend has been toward a drier and warmer climate.

Records of precipitation and temperature during the past several decades are in general accord with this trend, and existing glaciers have responded by melting back at a rather rapid rate.

It is logical, therefore, to consider climatic change as a possible cause of the observed instability and of the recent rejuvenation of erosion. If an area, which was once relatively stable, is rendered inherently unstable by climatic change, it would be highly susceptible to erosion resulting from poor land-use practices. Even moderate misuse of such areas would result in very serious damage. Therefore, it appears double important to evaluate carefully all natural factors in order to provide a sound basis for intelligent management of watershed lands.

FUTURE PLANS

Some analysts predict that the present period of "partial mobilization" will last for 15 or 20 years. Regardless of the length of time it covers, we can only guess its effect on the research program of the Rocky Mountain Station. If the all-out effort of 1942-45 is again necessary, we can look forward to very few advances in resource management. On the other hand, if partial mobilization means a more deliberate strengthening of the Nation by building our basic wealth, research should play an important part in it.

The Rocky Mountain Station has made plans to meet whatever situation develops. We know from experience where we can "hold the line" and how we can do it, if necessary. But, we have also drawn the blueprints with a more optimistic approach. They outline a research program which will help make our country more secure in the power to produce from natural resources.

Watershed Management

The goal of more usable water remains uppermost in our plans for watershed-management research. Present studies in water yield from forested basins will be maintained and, if at all possible, expanded to cover a range of conditions we are not now able to sample. Water-yielding areas of Wyoming and southern Colorado present needs for additional research, which would also provide a valuable adjunct to the present program at Fraser Experimental Forest. Research will place increased emphasis on the climatic and topographic conditions influencing snow-melt and snow evaporation; the effect of timber cutting on litter decomposition, soil-moisture deficits, and ground-water fluctuations. We plan also to include more investigations of improved road-building and logging methods, and to evaluate the contribution of alpine areas to water yields.

More usable water does not necessarily mean more yield. Often it implies the same quantity but improved quality. One of our biggest problems is to find means of boosting quality by reducing erosion and the silt content of streams. We plan to learn much more about the management of range and timberlands where erosion is a serious problem. At Manitou Experimental Forest and on the Western Slope, we have developed some standards of use, particularly on rangelands. They have served very well in defining broad management practices, but the need for more complete guides is critical.

Much range- and forest-watershed land has deteriorated to the point where more than just good management is needed for restoration. Low-cost, efficient control of gully, sheet, and streambank erosion must be developed. Revegetation is practicable in many cases, but there is a big job yet to do in selecting adaptable species and learning how best to propagate and establish them. Grading and mechanical contrivances are often necessary to increase the success and efficiency of vegetation, and they will not be overlooked as we develop our erosion-control studies. Small structures must also be developed to build up channel storage in headwater streams, particularly those which generate localized but destructive torrential flows.

We will continue to search for more ways to conserve water because shortages are developing over most of the region. We need to know more about the consumptive use of native plants and methods to replace water-loving plants by others having lower moisture demands.

River-basin programs will occupy ever-increasing importance in the American scene, and growing emphasis will be given to developments which depend on water resources. Continuing demands will be made upon research agencies like the Rocky Mountain Station for more statistical data and for improved methods of resource management. Our job is to foresee these needs and slant our program accordingly. We are doing this now, but much more is required.

Range Management

The management of grazing ranges must always be regarded as a dual-purpose enterprise. Usually ranges can be grazed and yet retain their functions as adequate watersheds. Our aim is to build up criteria for judging each range type so that we can be certain how much grazing use is allowable.

The problem does not end there, either. Within the limits of allowable use, there is some latitude for grazing practices. More pasture studies are needed to point out the most efficient methods for attaining the maximum in growth of forage and products from the livestock. In the Front Range, we lack these data for the steep-slope situations. Nor has any work been done for ranges on the Western Slope, in Wyoming, and in the tall-grass type of South Dakota, Kansas, and Nebraska.

There is an urgent need for intensifying our grazing-management studies in the Big Horn Mountains of Wyoming and in the plateau area of southwestern Colorado. Results obtained at the Central Plains Experimental Range and the Manitou Experimental Forest supply us with broad guides, but do not give enough specific information on local range problems to provide standards of good resource management.

More work will be done to improve the grazing capacity of native ranges and halt the deteriorating influences of erosion. Action programs in reseeding for forage production and soil-binding purposes are due for expansion. They have already developed faster than the pace of research. Clearly, we need an accelerated investigative program to discover adaptable

species and test them under field conditions. Inexpensive yet foolproof methods of seeding will be constantly explored. Where competition is a factor, newer and more efficient eradication procedures will continue to occupy much of our effort. Increased emphasis will be placed on erosion-control plantings on the Front Range and the Western Slope. All phases of reseeding need expansion in Wyoming.

Forest Management

More production is the watchword in forest-management research. We know that it is possible through management, but we have yet to completely develop the methods. For lodgepole pine, our plot trials at Fraser Experimental Forest have narrowed down the possibilities to one or two cutting procedures. Work in the Engelmann spruce-alpine fir type has not progressed this far yet, and final answers for both types are still some distance off.

For the next few years our forest-management research will be concentrated on lodgepole pine and spruce-fir types because of the relatively high potential of these species in timber production, and their close relation to water yields. The planned cutting of timber in Fool Creek will be given highest priority because of the vital importance of the project to both forest management and watershed management. In this single-package experiment, we have possible answers regarding the management of lodgepole pine and spruce-fir timber types, yields from timber cutting, erosion from skidding and hauling, and efficiency of logging methods.

Management of ponderosa pine in the region will receive long overdue attention when funds are available. If the opportunity arises, the first priority will be given to research in the Black Hills.

Future development of timber resources in the region will be greatly assisted by a thorough inventory. Our plans strongly emphasize this need.

Continued effort will be made by the Station to launch research in utilization of timber products. This will include studies designed to find new ways to reduce waste in the woods and at the mill, and to improve the accuracy and general quality of milling. A pilot-plant mill at Fraser Experimental Forest would serve admirably well to test and develop new techniques in manufacturing wood products.

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__________ and Vaughn, W. T. Controlling big sagebrush with 2,4-D and other chemicals. Journal of Range Management.

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Goodell, B. C. A trapezoidal flume for gaging mountain streams. Station Paper No. 2. June 1950.

Hull, A. C. Jr. Hints on eradication of big sagebrush (<u>Artemisia</u> <u>tridentata</u>) by chemical spraying and by burning. October 1950.

__________ and Doran, C. W. Observations on equipment and methods for brush control. Range Research Mimeograph. December 1950.

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__________ and Hull, A. C. Jr. How to reseed parks and openings in the ponderosa pine zone of Colorado. Station Paper No. 3. June 1950.

STATION PERSONNEL
(As of December 31, 1950)

Administration	
W. G. McGinnies	Director
C. L. Newman	Administrative Assistant
Marie D. Garwood	Secretary
Mona F. Nickerson	Clerk-Stenographer
Elizabeth J. Kreycik	Clerk-Typist
Marie D. Hanawalt	Clerk-Typist
Special Soils Investigations	
John L. Retzer	Soils Scientist
Forest Management	
Bert R. Lexen, Division Chief	Research Forester
Raymond J. Boyd, Jr.	Research Forester
Joye E. Smith	Research Forester
Forest Influences	
L. Dudley Love, Division Chief	Forester
E. G. Dunford	Forester
Range Research	
David F. Costello, Division Chief	Range Conservationist
Alvin C. Hull, Jr.	Range Conservationist
Neland A. Kissinger, Jr.	Range Conservationist

Research Centers

Continental Divide, (Fraser Experimental Forest)	Fraser, Colorado
Bert R. Lexen, Acting RCL	Research Forester
Raymond J. Boyd, Jr.	Research Forester
Harry E. Brown	Research Forester
Western Slope, Delta, Colorado	
George T. Turner, Acting RCL	Range Conservationist
Edward J. Dortignac	Forester
Clyde W. Doran	Range Conservationist
Alice J. Gaskins	Clerk-Stenographer

Experimental Forests and Ranges

Manitou Experimental Forest, Woodland Park, Colorado	
W. M. Johnson, in charge	Range Conservationist
Thorkild W. Hansen	Forestry Aid
Central Plains Experimental Range, Nunn, Colorado	
G. E. Klipple, in charge	Range Conservationist

Collaborators

D. V. Harris	Geologist, in cooperation with Colorado A & M College
H. L. Shantz	U. S. Forest Service (retired)

Summer Field Assistants - 1950

Colorado A & M College	
Robert Alexander	Continental Divide Research Center
Herbert M. Berndt	Western Slope Research Center
Roger M. Blouch	Central Plains Experimental Range
Richard Driscoll	Western Slope Research Center
John H. Ehrenreich	Fort Collins, Colorado
Donald A. Jameson	Fort Collins, Colorado
Frank Ronco, Jr.	Fort Collins, Colorado
Juergen E. Schoeler	Western Slope Research Center
Richard E. Swan	Fort Collins, Colorado
Michigan State College	
Milton D. McClure	Continental Divide Research Center
Edgar H. Palpant	Western Slope Research Center
Montana State University	
Melvin Feinblum	Western Slope Research Center
Texas A & M College	
Richard K. Dewey	Manitou Experimental Forest
University of California	
Clyde A. Coggins	Manitou Experimental Forest
University of Michigan	
Donald Satterlund	Continental Divide Research Center
Utah State Agricultural College	
Gordon E. Gatherum	Central Plains Experimental Range

COOPERATING AGENCIES

Bureau of Entomology and Plant Quarantine

N. D. Wygant, in charge	Entomologist
Calvin Massey	Entomologist
W. F. McCambridge	Forestry Aid
E. P. Merkel	Entomologist
B. H. Wilford	Entomologist
Betty B. Fattor	Clerk

U. S. Fish and Wildlife Service

______________, in charge	Biologist

Bureau of Plant Industry, Soils, & Agricultural Engineering

Ross W. Davidson	Pathologist